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## Human Factors Topics in Flight Simulation: An Annotated Bibliography

by

S.Hunter, A.J.Gundry and J.M.Rolfe

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ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT  
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AGARD Report No. 656

6 HUMAN FACTORS TOPICS IN FLIGHT SIMULATION:  
AN ANNOTATED BIBLIOGRAPHY

by

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### SUMMARY

↓ This bibliography contains 504 references, with summaries, to reports concerned with human factors topics in flight simulation. Reports dealing solely with the engineering aspects of flight simulation have been excluded, unless they contain items of human factors interest. The bibliography, covering the years 1940 to 1976, is mainly comprised of English-language reports and contains no reference to classified material. ↑

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## INTRODUCTION

This bibliography is the result of the involvement of the Flight Skills Section of the Royal Air Force Institute of Aviation Medicine in flight simulation over the past fifteen years. The collection of human factors reports built up over this time made possible the production in 1974 of a Bibliography of Human Factors Research Using Flight Simulators (IAM Scientific Memorandum No. 119). Over the ensuing three years the bibliography has been extended and reviewed, and it now contains a greater number of reports which are accompanied by non-evaluative summaries. The present volume will, it is hoped, be a useful source of reference for those concerned with the design and use of flight simulators for pilot training, as well as those interested in the human factors aspects of aircraft design and operation which have been studied using flight simulators.

## ACKNOWLEDGEMENTS

The availability of library facilities was essential to the compilation of this bibliography. The authors wish to acknowledge the considerable help they have received from Miss E. Greenway and Mr C M Hobson of the IAM library, and the staff of the Royal Aircraft Establishment library.

The production of this bibliography in its present form was made possible by the Aerospace Medical Panel and the Publications Committee of AGARD; the authors gratefully acknowledge their assistance.

## ORGANISATION

The bibliography comprises an author index followed by a subject index. The author index is in alphabetical order by first author name, and gives the author(s), title, source and date, followed by the subject category. The subject category refers to the subject index, and shows where the reference, accompanied by summary, can be found.

Subjects are classified under seven headings, namely GENERAL & THEORETICAL, TRAINING, VISUAL CUES, MOTION CUES, HUMAN PERFORMANCE, CONTROLS & DISPLAYS, AIRCRAFT HANDLING. Within each category the references are in alphabetical order by first author's name. Within the subject index a few reports are cross referenced. Where it was thought that a report should be included in two subject categories, the reference and summary are to be found under the category thought most appropriate. The entry under the other subject category is the reference alone, followed by the subject category showing where the reference and summary may be found. A brief description of the contents of each subject category is given below:

**General & Theoretical** (65 entries) Review articles and discussions of applications for flight simulation. General assessments of the value of simulators. Experimental studies concerned with a variety of human factors issues.

**Training** (96 entries) Evaluations of the training effectiveness of flight simulation-based systems. Research reports and discussions of flight trainers and training technology, and the application of training theory to flight simulation.

**Visual Cues** (41 entries) Discussions, evaluations and research reports concerned with providing the simulator operator with an outside-cockpit visual scene.

**Motion Cues** (80 entries) Discussion, evaluations and research reports concerned with simulating the force environment encountered in flight.

**Human Performance** (65 entries) Studies using flight simulators in the definition of the limitations and characteristics of pilot performance, the action of stressors (fatigue, drugs, environment), the measurement of workload, and the description of pilot control behaviour.

**Controls & Displays** (79 entries) Human factors research using flight simulators to evaluate aircraft cockpit controls, control system and displays.

**Aircraft Handling** (78 entries) Simulator evaluation of aircraft handling qualities.

## ABBREVIATIONS

Listed below are the abbreviations and full addresses of the organisations from whom reports have originated:

AD	Astia Documentation number, quoted in the absence of a fuller source reference. Enquiries about these reports should be made, quoting the AD number, to the documentation organisations listed in Appendix A.
AFFDL	Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio 45433, USA.
AFHRL	Air Force Human Resources Laboratory, Air Force Systems Command, Brooks Air Force Base, Texas 78235, USA.
AFOSR	Air Force Office of Scientific Research, 1400 Wilson Boulevard, Arlington, Virginia 22209, USA.
AFPTRC	Air Force Personnel and Training Research Center, Randolph Air Force Base, Texas, USA.
AGARD	Advisory Group for Aerospace Research and Development, 7 rue Ancelle, 92200 Neuilly sur Seine, France.
AHS	American Helicopter Society, 30 East 42nd Street, New York, N.Y. 10017, USA.
AIAA	American Institute of Aeronautics and Astronautics, Technical Information Service, 750 3rd Avenue, New York, N.Y. 10017, USA.
AMRL	Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio 45433, USA.
ARL	Aviation Research Laboratory, Institute of Aviation, University of Illinois, Willard Airport, Savoy, Illinois 61874, USA.
ASD	Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio 45433, USA.
BHC	Bell Helicopter Company, P.O. Box 482, Fort Worth, Texas 76101, USA.
CAL	Cornell Aeronautical Laboratory Inc., Buffalo, N.Y., USA.
DFVLR	Deutsche Forschungs und Versuchsanstalt für Luft und Raumfahrt, D5050 Porz-Wahn, Linde Hohe, W. Germany.
DGLR	Deutsche Gesellschaft für Luft und Raumfahrt, 5 Köln 51, Goethestrasse 10, W. Germany.
FAA	Federal Aviation Administration, Washington D.C. 20591, USA.
FPRC	Flying Personnel Research Committee, Ministry of Defence (Air), 1-6 Tavistock Square, London WC1H 9NL, UK.
HMSO	Her Majesty's Stationery Office, Cornwall House, Stamford Street, London SE1 9NY, UK.
HumRRO	Human Resources Research Organisation, 300 North Washington Street, Alexandria, Virginia 22314, USA.
IATA	International Air Transport Association P.O. Box 550, 1000 Sherbrooke Street West, Montreal P.Q. H3A 2R4, Canada.
IAM	RAF Institute of Aviation Medicine, Farnborough, Hants GU14 6SZ, UK.
IEE	Institution of Electrical Engineers, Savoy Place, London WC2R 0BL, UK.
IEEE	Institute of Electrical and Electronics Engineers Inc., 345 East 47th Street, New York, N.Y. 10017, USA.
MoA	Ministry of Aviation now Ministry of Defence (Procurement Executive), St Giles Court, 1-13 St Giles High Street, London WC2H 8LD, UK.
NA	North American Aviation Inc., Columbus 16, Ohio, USA.

NADC	Naval Air Development Center, Warminster, Pennsylvania 18974, USA.
NASA	National Aeronautics and Space Administration, Scientific and Technical Information Office, Washington DC 20546, USA.
NAVTRAEQUIPCEN	Naval Training Equipment Center, Orlando, Florida 32813, USA.
NTDC	Naval Training Device Center, now NAVTRAEQUIPCEN, as above.
RAE	Royal Aircraft Establishment, Farnborough, Hants GU14 6TD, UK.
RAeS	Royal Aeronautical Society, 4 Hamilton Place, London W1V 0BQ, UK.
SAE	Society of Automotive Engineers Inc., 2 Pennsylvania Plaza, New York, N.Y. 10001, USA.
SAM	School of Aviation Medicine, Brooks Air Force Base, Texas 78235, USA.
SDC	Special Devices Center, Office of Naval Research, Port Washington, N.Y. 11050, USA.
STI	Systems Technology Inc., 13766 South Hawthorne Boulevard, Hawthorne, California 90250, USA.
TRECOM or ATRECOM	US Army Transportation Research Command, Fort Eustis, Virginia, USA.
WADC	Wright Air Development Center, Wright-Patterson Air Force Base, Ohio 45433, USA.

Abbreviations may form part of the reference number, and are used by some organisations to distinguish between different types of report. These abbreviations may be used as quoted and are in each case correct for the originating organisation. The more common abbreviations are listed below:

CP	Conference Proceedings	TM	Technical Memorandum
CR	Contractor Report	TN	Technical Note
R	Report	TR	Technical Report
S	Scientific Memorandum	TT	Technical Translation
SP	Special Publication		

**AUTHOR INDEX**

ABBOT, B.A. and DOUGHERTY, D.J. *JANAIR - Contact analogue simulator evaluation: Altitude and ground speed judgements.* BHC D-228-421-015, 1964. CONTROLS and DISPLAYS.

ACKLAM, D.J. *Flight simulator as a design tool.* Aircraft Engineering, 1972, 44, 4-8. AIRCRAFT HANDLING.

ADAMS, A.H., HUDDLESTON, H.F., ROBSON, B.M. and WILSON, R.V. *Some effects of sleep loss on a simulated flying task.* RAE TR-72168, 1972. HUMAN PERFORMANCE.

ADAMS, J.J., BERGERON, H.P. and HURT, G.J. *Human transfer functions in multi-axis and multi-loop control systems.* NASA TN D-3305, 1966. HUMAN PERFORMANCE.

ADAMS, J.J. and HUFFORD, L.E. *Effects of programmed perceptual training on the learning of contact landing skills.* NTDC 297-3, April 1961. VISUAL CUES.

ADAMS, J.J., HUFFORD, L.E. and DUNLOP, J.M. *Part- versus whole-task learning of a flight manoeuvre.* NTDC 297-1, June 1960. TRAINING.

ADAMS, J.J., KINCAID, J.K. and BERGERON, H.P. *Determination of critical tracking tasks for a human pilot.* NASA TN D-3242, February 1966. AIRCRAFT HANDLING.

A'HARRAH, R.C. and SCHULZE, R.P. *An investigation of low-altitude high-speed flying and riding qualities of aircraft.* NA-62H-397, February 1963. AIRCRAFT HANDLING.

AIKEN, E.W. and SCHULER, J.M. *A fixed-based ground simulator study of control and display requirements for VTOL instrument landings with a decelerating approach to a hover.* Final Report. Calspan Corp., Buffalo, New York, USA. CALSPAN AK-5113-F-2, 1974. CONTROLS and DISPLAYS.

ALBERY, W.B., GUM, D.R. and HUNTER, E.D. *Future trends and plans in motion and force simulation development in the Air Force.* Proceedings of AIAA. Visual and Motion Simulation Conference, Dayton, Ohio, USA, April 1976. MOTION CUES.

ALLISON, W.A. *Naval Air Test Centre participation in development of air-to-air combat simulation.* AIAA 72-765, 1972. GENERAL and THEORETICAL.

ALLRED, G.A. *Future trends in aircraft simulation.* British Airline Pilots' Association Technical Symposium, Middlesex, England, November 1968. GENERAL and THEORETICAL.

AMMERMAN, L.R. *Evaluation of an integrated electronic instrument display for helicopter hover operations using a six-degree-of-freedom fixed-base simulation.* AD A010834, 1975. CONTROLS and DISPLAYS.

ANGELL, D., SHEARER, J.W. and BERLINER, D.C. *Study of training performance evaluation techniques.* NTDC 1449-1, October 1964. TRAINING.

ANNIN, G.D. *The influence of piloted flight simulator studies on the design of the SST instruments.* SAE 670306, 1967. CONTROLS and DISPLAYS.

ARMSTRONG, B.D. *Difficulties with the simulation of aircraft landings.* RAE TR-68116, 1968. AIRCRAFT HANDLING.

ARMSTRONG, B.D. and MUSKER, G. *Training for low visibility landings.* Proceedings of R.Ae.S. Symposium 'Flight Training Simulators for the 70s', London, England, October 1970. VISUAL CUES.

BARNES, A.G. *The objectives of simulation.* AGARD CP-79-70, 1971. AIRCRAFT HANDLING.

BARNES, A.G., HOUGHTON, D.E.A. and COLCLOUGH, C. *A simulator study of direct lift control (DLC).* MOD CP-1199, 1970. AIRCRAFT HANDLING.

BARRETT, G.V., CABE, P.A., THORNTON, C.L. and KERBER, H.E. *Evaluation of a motion simulator not requiring cockpit motion.* Human Factors, 1969, 11, 239-244. MOTION CUES.

BATY, D.L. *Evaluating a CRT map predictor for airborne use.* IEEE Transactions on Systems, Man and Cybernetics. SMC-6, 209-215, 1976. CONTROLS and DISPLAYS.

BATY, D.L., WEMPE, T.E. and HUFF, E.M. *A study on aircraft map display location and orientation.* IEEE Transactions on Systems, Man and Cybernetics. SMC-4, 560-568, 1974. CONTROLS and DISPLAYS.

BECK, L.J. *The effect of spurious angular accelerations on tracking in dynamic simulation.* Human Factors, 1974, 16, 423-431. MOTION CUES.

BELLM, R.H.J. *An appraisal of current shortcomings in the procurement and commissioning processing of flight simulators.* Proceedings of R.Ae.S. Symposium 'Flight Training Simulators for the 70s', London, England, October 1970. GENERAL and THEORETICAL.

BELSLEY, S.E. *Pilot-vehicle system simulation.* AGARDograph 99, 1964. AIRCRAFT HANDLING.

BENSON, J.A. and DE TALLY, W.A. *Air navigator training system design.* Institute of Navigation 25th Anniversary Year Meeting, USAF Academy, Colorado Springs, Colorado, U.S.A., July 1970. TRAINING.

DeBERG, O.H., McFARLAND, B.P. and SHOWALTER, T.W. *The effect of simulator fidelity on engine failure training in the KC-135 aircraft.* Proceedings of AIAA Visual and Motion Simulation Conference, Dayton, Ohio, U.S.A., April 1976. MOTION CUES.

BERGER, J.B., MEYER, R.P. and CARLTON, D.L. *Application of manned air combat simulation in the development of flight control requirements for weapon delivery.* Proceedings of AGARD FMP/GCP Symposium 'Flight Simulation/ Guidance Systems Simulation', The Hague, Netherlands, October 1975. AIRCRAFT HANDLING.

BERGERON, H.P. and ADAMS, J.J. *Measured transfer functions of pilots during two-axis tasks with motion.* NASA TN-D-2177, 1964. MOTION CUES.

BERGERON, H.P., ADAMS, J.J. and HURT, G.J. *The effects of motion cues and motion scaling on one- and two-axis compensatory control tasks.* NASA TN-D-6110, 1971. MOTION CUES.

BERGERON, H.P. and HOLT, J.D. *Motion-base simulator tests of low-frequency aircraft motion on the passenger ride environment.* NASA TM-X-62464, 1975. MOTION CUES.

BERGSTROM, B. and HUDDLESTON, H.F. *HUD evaluation by limited flight simulation: Simplified SAAB 37 and Specto Kestrel aircraft displays.* IAM R-398, 1967. CONTROLS and DISPLAYS.

BERINGER, D.B., WILLIGES, R.C. and ROSCOE, S.N. *The transition of experienced pilots to a frequency-separated aircraft attitude display.* Human Factors Society 18th Annual Meeting, Huntsville, Alabama, U.S.A., October 1974. CONTROLS and DISPLAYS.

BESCO, R.O. *The effects of cockpit vertical accelerations on a simple piloted tracking task.* NA-61-47, 1961. MOTION CUES.

BEUTLER, G.C. *Training airline flight crews.* IEEE Transactions on Education. E-15, 129-133, 1972. TRAINING.

BIHRLE, W. *Aircraft characteristics that influence the longitudinal handling qualities during a carrier approach.* AIAA 69-894, 1969. AIRCRAFT HANDLING.

De BILLIS, W.B. *Flight information scale test for heads-up and panel mounted displays.* Human Engineering Laboratories, Aberdeen Proving Ground, Maryland, U.S.A. HEL-TM-22-73, 1973. CONTROLS and DISPLAYS.

BLAIWES, A.S., PUIG, J.A. and REGAN, J.J. *Transfer of training and the measurement of training effectiveness.* Human Factors, 1973, 15, 523-533. TRAINING.

BORLACE, F.H. *Flight simulator motion, its enhancement and potential for flight crew training.* SAE 670304, April 1967. MOTION CUES.

BOWEN, H.M., BISHOP, E.W., PROMISEL, D. and ROBINS, J.E. *Study, assessment of pilot proficiency.* NTDC 1614-1, 1966. TRAINING.

BOWEN, H.M., HALE, A. and KELLEY, C.R. *Tracking training V: Field study of the training effectiveness of the general vehicular research tool.* NTDC 955-1, 1962. TRAINING.

BRAY, R.S. *Experience with visual simulation in landing and take-off research.* AGARDograph 99, 1964. VISUAL CUES.

BRAY, R.S. *A study of vertical motion requirements for landing simulation.* Human Factors, 1973, 15, 561-568. MOTION CUES.

BRAY, R.S. and ANDERSON, S.B. *Simulation techniques used in investigating aircraft accidents*. Proceedings of R.Ae.S Conference on Atmospheric Turbulence, London, England, May 1971. AIRCRAFT HANDLING.

BRAY, R.S., DRINKWATER, F.J. and EMMETT, B.F. *The influence of motion on the effectiveness of flight simulators in training manoeuvres*. Proceedings of NASA Aircraft Safety and Operating Problems Conference, Vol 1, 207-220, 1971. MOTION CUES.

BREUHAUS, W.O. and HARPER, R.P. *The selection of tasks and subjects for flight simulation experiments*. AGARD CP-79-70, 1971. AIRCRAFT HANDLING.

BREUL, H.T. *Simulator study of low speed VTOL handling qualities in turbulence (Final Report)*. Grumman Aircraft Corporation, Bethpage, New York, U.S.A. Research Report RE 238, February 1966. AIRCRAFT HANDLING.

BRIGGS, G.E. and WIENER, E.L. *Fidelity of simulation: I. Time-sharing requirements and control loading as factors in transfer of training*. NTDC 508-4, 1959. CONTROLS and DISPLAYS.

BRISSENDEN, R.F. *Using simulation for research - and using research to develop valid simulation techniques*. SAE 670309, 1967. GENERAL and THEORETICAL.

BROCKER, D.H. and GANZLER, B.C. *HUD for the Flight Simulator for Advanced Aircraft (FSAA)*. NASA TM-X-62416, 1975. CONTROLS and DISPLAYS.

BROWN, A.D. *Category 2 - A simulation study of approaches and landings at night*. RAE Tech. Memo: Avionics 59 (BLEU), 1970. AIRCRAFT HANDLING.

BROWN, A.D. *An examination of simulator landing problems*. AIAA 70-344, 1970. AIRCRAFT HANDLING.

BROWN, J.L. *Visual elements in flight simulation*. Centre for Visual Science, University of Rochester, New York 14627, U.S.A. Technical Report 73-2, December 1973. VISUAL CUES.

BROWN, B.P., JOHNSON, H.I. and MUNGALL, R.G. *Simulator motion effects on a pilot's ability to perform a precise longitudinal flying task*. NASA TN-D-367, 1960. MOTION CUES.

BROWN, J.L., KUEHNEL, H., NICHOLSON, F.T. and FUTTERWEIT, A. *Comparison of tracking performance in the TV-2 aircraft and the ACL computer/AMAL human centrifuge simulation of this aircraft*. NADC-MA-6010/ NADC-AC-6008, November 1960. MOTION CUES.

BROWN, E.L., MATHENY, W.G. and FLEXMAN, R.E. *Evaluation of the School Link as an aid in teaching ground reference manoeuvres*. SDC 71-16-7. 1950. TRAINING.

BROWNING, R.F. and RYAN, L.E. *Training analysis of P-3 replacement pilots and flight engineer training. Final Report*. NAVTRAEQUIPCEN TAEG-10, 1973. TRAINING.

BRUGH, R.L. and McHUGH, J.G. *Flight simulator study of human performance during low-altitude high-speed flight*. TRECOM 63-52, 1963. HUMAN PERFORMANCE.

BRUNING, G. *Simulation, an introduction and survey*. AGARD CP-79-70, 1971. GENERAL and THEORETICAL.

BUCCHOUT, R., SHERMAN, H., GOLDSMITH, C.T. and VITALE, P.A. *The effects of variations in motion fidelity during training on simulated low-altitude flight*. AMRL-TDR-63-108, 1963. MOTION CUES.

BURROWS, A.A. *Human factors in flight training*. Flight Safety Foundation 21st Annual International Air Safety Seminar, Anaheim, California, U.S.A., October 1968. GENERAL and THEORETICAL.

CACIOPPO, A.J. *Pilot information utilisation: a study in human response dynamics*. Goodyear Aircraft Corporation, Akron 15, Ohio, U.S.A. Technical Report GER 7686, 1963. HUMAN PERFORMANCE.

CALLAN, W.M., HOUCK, J.A. and DI CARLO, D.J. *Simulation study of intra-city helicopter operations under instrument conditions to Cat 1 minima*. NASA TN-D-7786, 1974. HUMAN PERFORMANCE.

CARBONELL, J.R., WARD, J.L. and SENDERS, J.W. *A queueing model of visual sampling: Experimental validation*. IEEE Transactions on Man-Machine Systems. MMS-9, 56-60, 1968. HUMAN PERFORMANCE.

CARLSON, E.F. *Direct Sideforce Control for improved weapon delivery accuracy*. AIAA 74-10, 1974. CONTROLS and DISPLAYS.

CARO, P.W. *Equipment-device task commonality analysis and transfer of training*. HumRRO TR-70-7, 1970. TRAINING.

CARO, P.W. *An innovative instrument flight training programme*. HumRRO PP-16-71, 1971. TRAINING.

CARO, P.W. *Aircraft simulators and pilot training*. Human Factors, 1973, 15, 502-509. TRAINING.

CARO, P.W. *Some factors influencing transfer of simulator training*. Proceedings of R.Ae.S. Third Flight Symposium, London, England, April 1976. TRAINING.

CARO, P.W. and ISLEY, R.N. *Helicopter trainee performance following synthetic flight training*. HumRRO PP-7-66, 1966. TRAINING.

CARO, P.W., ISLEY, R.N. and JOLLEY, O.B. *The captive helicopter as a training device: Experimental evaluation of a concept*. HumRRO TR-68-9, 1968. TRAINING.

CARO, P.W., ISLEY, R.N. and JOLLEY, O.B. *Research on synthetic training: Device evaluation and training programme development*. HumRRO TR-73-20, 1973. TRAINING.

CARO, P.W., JOLLEY, O.B., ISLEY, R.N. and WRIGHT, R.H. *Determining training device requirements in fixed wing aviator training*. HumRRO TR-72-11, 1972. TRAINING.

CARROLL, J.J. and ZEISMER, R. *SST training programme considerations*. SAE 670307, 1967. TRAINING.

CHAPPELOW, J.W. and LAKIN, T. *Pilot opinion on simulation*. Proceedings of R.Ae.S. Second Flight Symposium, London, England, May 1973. GENERAL and THEORETICAL.

CHARLES, J.P., JOHNSON, R.M. and SWINK, J.R. *Automated flight training (AFT) GCI/CIC air attack*. Final Report Feb 1972-Jul 1973. NAVTRAEQUIPCEN 72-C-0108-1, 1973. TRAINING.

CHASE, W.D. *Effect of colour on pilot performance and transfer functions using a full-spectrum, calligraphic, colour display system*. Proceedings of AIAA Visual and Motion Simulation Conference, Dayton, Ohio, U.S.A., (loose paper), April 1976. VISUAL CUES.

CHUBBOY, R.A. *Programme plan to develop airworthiness standards for STOL aircraft*. Canadian Aeronautics and Space Journal, 1973, 19, 289-295. AIRCRAFT HANDLING.

CLARK, C.C. and WOODLING, C.H. *Centrifuge simulation of the X-15 research aircraft*. NADC R-9, December 1959. MOTION CUES.

CLEMENT, W.F., HOFMANN, L.G. and GRAHAM, D. *A direct procedure for partitioning scanning workload with a flight director*. Proceedings of IEEE 'Cybernetics and Society' International Conference, Boston, Massachusetts, U.S.A., November 1973. HUMAN PERFORMANCE.

COHEN, E. *How much motion is really needed in flight simulators?* SAE 710488, 1971. MOTION CUES.

COHEN, E. *Simulators - a training viewpoint*. Flight Simulation Operations, Singer-Link Corporation, Binghamton, New York, U.S.A., Technical Newsletter No.1, 1972. GENERAL and THEORETICAL.

COLLIN, M.A.B. *The simulator industry and its contribution to military training requirements*. Proceedings of R.Ae.S. Second Flight Simulation Symposium, London, England, May 1973. GENERAL and THEORETICAL.

COLMAN, K.W., DAVIS, C.G. and COURTNEY, D. *The Operational Flight Trainer in aviation safety*. NTDC 520-1, July 1962. GENERAL and THEORETICAL.

CONANT, J. *Universal Aircraft Flight Simulator/Trainer system definition*. Final technical report. Oct 1969-Sept 1970. ASD TR-70-28, 1970. GENERAL and THEORETICAL.

COOLES, H.D. *The dynamic flight simulator - a general purpose research tool*. Proceedings of Instrument Society of America Eleventh National Aerospace Instrument Symposium, Los Angeles, U.S.A., October 1965. AIRCRAFT HANDLING.

COOPER, G.E. and DRINKWATER, F.J. *Pilot assessment aspects of simulation*. NASA TM-X-66583, 1971. AIRCRAFT HANDLING.

CORKINDALE, K.G.G. *A flight simulator study of missile control performance as a function of concurrent workload.* AGARD CP-146, 1974. HUMAN PERFORMANCE.

CREELMAN, J.A. *Evaluation of approach training procedures.* U.S. Naval School of Aviation Medicine, Naval Air Station, Pensacola, Florida, U.S.A., Technical Report AD 89-997, October 1959. TRAINING.

CREER, B.Y., SMEDAL, H.A. and WINGROVE, R.C. *Centrifuge study of pilot tolerance to acceleration and the effects of acceleration on pilot performance.* NASA TN-D-337, 1960. HUMAN PERFORMANCE.

CREER, B.Y., STEWART, J.D., MERRICK, R.B. and DRINKWATER, F.J. *A pilot opinion study of lateral control requirements for a fighter-type aircraft.* NASA M-1-29-59A, 1959. AIRCRAFT HANDLING.

CROOK, W.G. *Experimental assessment of ground trainers in general aviation pilot training.* FAA ADS-67-5, 1967. TRAINING.

CROOK, W.G. *Development of low-cost cockpit/outside time-sharing training equipment.* FAA RD-72-95, 1972. HUMAN PERFORMANCE.

CROSS, K.D. and CAVALLERO, F.R. *Utility of the vertical contact analogue display (VCAD) for carrier landings: A diagnostic evaluation.* AGARD CP-96, 1972. CONTROLS and DISPLAYS.

CURRY, R.E., YOUNG, L.R., HOFFMAN, W.C. and KUGEL, D.L. *A pilot model with visual and motion cues.* Proceedings of AIAA Visual and Motion Simulation Conference, Dayton, Ohio, U.S.A., April 1976. HUMAN PERFORMANCE.

CURTIN, J.G., EMERY, J.H. and DRENNEN, T.G. *Investigation of manual control in secondary flight tracking tasks.* Annual Technical Report. McDonnell-Douglas Aerospace Corporation, Louisville, Montana, U.S.A. MDC E-0890, 1973. CONTROLS and DISPLAYS.

CUSHMAN, W.H. *Cumulative flashblindness effects produced by multiple high intensity flashes.* Aerospace Medicine, 1971, 42, 763-767. HUMAN PERFORMANCE.

DACHERY, M. and BRANDET, C. *The training centre for naval aviation navigation.* Navigation (Paris), 1975, 23, 310-323, In French. TRAINING.

DANNESKJOLD, R.D. *Objective scoring procedure for operational flight trainer performance.* SDC 999-2-4, 1956. TRAINING.

DAVIES, D.P. *Approval of flight simulator flying qualities.* Aeronautical Journal, 1975, 79, 281-297. GENERAL and THEORETICAL.

DAVIS, D.R. *Pilot error.* Air Ministry AP 3139A HMSO. 1948. HUMAN PERFORMANCE.

DAVIS, J. and BEADSMOORE, E.J. *A military view of flight simulation.* Proceedings of R.Ae.S. Symposium 'Flight Training Simulators for the 70s', London, England, October 1970. GENERAL and THEORETICAL.

DAVYDOV, V.V. *Psychophysiological features of the perception of instrument information by the pilot after diverting his attention to external features.* Voenno-Meditsinskii Zhurnal, Nov., 1970, 50-53. (In Russian). HUMAN PERFORMANCE.

DECKERT, W.H. and HOLZHAUSER, C.A. *Evaluation of V/STOL research aircraft design.* SAE 730947, 1973. AIRCRAFT HANDLING.

DEMAREE, R.G., NORMAN, D.A. and MATHENY, W.G. *An experimental programme for relating transfer of training to pilot performance and degree of simulation.* NTDC 1388-1, June 1965. TRAINING.

DEMPSEY, T.K. and LEATHERWOOD, J.D. *Vibration simulator studies for the development of passenger ride comfort criteria.* NASA TM-X-3295, 1975. MOTION CUES.

DILLENSCHNEIDER, P.G. and SHAW, A.W. *Use of ground-based simulators in aircraft design.* Journal of Aircraft, 1971, 8, 113-119. AIRCRAFT HANDLING.

DOUGHERTY, D.J., HOUSTON, R.C. and NICKLAS, D.R. *Transfer of training in flight procedures from selected ground training devices to the aircraft.* NTDC 71-16-16, September 1957. TRAINING.

DOUVILLIER, J.G., TURNER, H.L., McLEAN, J.D. and HEINLE, D.R. *Effects of flight simulator motion on pilot's performance of tracking tasks.* NASA TN-D-143, 1960. MOTION CUES.

DRAKE, D.E., BERG, R.A., TEPER, G.L. and SHIRLEY, A. *A flight simulator study of STOL transport lateral control characteristics.* FAA RD-70-61, 1970. AIRCRAFT HANDLING.

DREW, G.C. *An experimental study of mental fatigue.* FPRC 227, 1940. HUMAN PERFORMANCE.

DUNFORD, M.J. *The continuing case for aircraft training.* Aircraft Engineering, 1976, 48, 11-13. TRAINING.

DUSTERBERRY, J.C. *Manned flight simulation facilities.* AGARDograph 99, 1964. AIRCRAFT HANDLING.

DYDA, K.J. and LEFRITZ, N.M. *Factors affecting pilot landing techniques.* NA-66-811, 1966. HUMAN PERFORMANCE.

EDENBOROUGH, R.A. *User opinion of RAF flight simulators.* IAM R-433, 1968. GENERAL and THEORETICAL.

EDENBOROUGH, R.A. and HAMMERTON-FRASER, A.M. *A flight simulator comparison of two methods of displaying altitude and vertical speed information.* IAM R-397, 1969. CONTROLS and DISPLAYS.

EDWARDS, F.L.M. *Designing to satisfy the increased demands in flight simulation.* Civil Aviation Safety Centre Fifth Annual Technical Conference, Beirut, Lebanon, September-October 1970. GENERAL and THEORETICAL.

ELLIS, N.C., LOWES, A.L., MATHENY, W.G. and NORMAN, D.A. *Pilot performance, transfer of training and degree of simulation: III Performance of non-jet-experienced pilots versus simulation fidelity.* NTDC 67-C-0034-1, 1968. TRAINING.

ELLIS, N.C., LOWES, A.L., MATHENY, W.G. and NORMAN, D.A. *The feasibility of using an adaptive technique in flight simulator training.* Ergonomics, 1971, 14, 381-389. TRAINING.

ELLIS, N.C., LOWES, A.L., MATHENY, W.G., NORMAN, D.A. and WILKERSON, L.E. *Pilot performance, transfer of training, and degree of simulation: II Variations in aerodynamic coefficients.* NTDC 1889-1, May 1967. TRAINING.

EMERY, J.H. and DOUGHERTY, D.J. *Contact analogue simulator evaluation: Climbout, hover, cruise and descent manoeuvres.* BHC D228-421-017, 1964a. CONTROLS and DISPLAYS.

EMERY, J.H. and DOUGHERTY, D.J. *Contact analogue simulator evaluation: Vertical display with horizontal map display.* BHC D228-421-020, 1964b. CONTROLS and DISPLAYS.

EMERY, J.H., KOCH, C.A. and CURTIN, J.G. *Contact analogue simulator evaluation: Investigation of director symbols, display alteration, and the presentation of secondary flight information.* BHC D228-420-008, 1967. CONTROLS and DISPLAYS.

ERDMAN, F. and DIERKE, R. *The effect of motion cues on guidance errors during simulated ILS approaches.* DGLR 70-071, 1970. (In German). MOTION CUES.

ETO, D.K., STREETER, E. and WEBER, J.W. *Tactical data systems design concepts evaluation.* R & D Report April 1973-March 1974. AFFDL TR-74-53, 1974. CONTROLS and DISPLAYS.

EYER, S.W. and IVERS, J.B. *The effect of alcohol upon Link trainer performance.* Naval Medical Research Institute, National Naval Medical Centre, Bethesda, Maryland, U.S.A. Project NM 001 056.06.01, June 1950. HUMAN PERFORMANCE.

FAUSET, I.D. *The quantitative evaluation of aircraft flight simulators.* Aviation Psychological Research Centre, Western European Association for Aviation Psychology, Brussels, Belgium. 1973. GENERAL and THEORETICAL.

- FAYE, A.E. *Attitude control requirements for hovering, determined through the use of a piloted flight simulator.* NASA TN-D-742, 1961. AIRCRAFT HANDLING.
- FEDDERSON, W.E. *The role of motion information and its contribution to simulator validity.* BHC D228-429-001, 1962. MOTION CUES.
- FERRARESE, J.A. *Assessment of new training systems as substitutes for airborne trainings.* SAE 710476, 1971. GENERAL and THEORETICAL.
- FERROL, M. *Defining synthetics.* Shell Aviation News, 1975, 427, 11-14. GENERAL and THEORETICAL.
- FLEXMAN, R.E. *Man in the middle. A primer in simulation.* The Connecting Link, 1965, 2(1). Singer-Link Corporation, Binghamton, New York, U.S.A. GENERAL and THEORETICAL.
- FLEXMAN, R.E. *Man in motion.* The Connecting Link, 1966, 3, 12-18. Singer-Link Corporation, Binghamton, New York, U.S.A. MOTION CUES.
- FLEXMAN, R.E. *Advanced training concepts in simulation.* Proceedings of Twenty-first Flight Safety Foundation Annual International Air Safety Seminar, Anaheim, California, U.S.A., October 1968. TRAINING.
- FLEXMAN, R.E. and LATHAM, A.J. *Use of a contact flight simulator in training of basic student pilots.* HumRRO RN-Pilot-52-1. 1952. TRAINING.
- FLEXMAN, R.E., ROSCOE, S.N., WILLIAMS, A.C. and WILLIGES, B.H. *Studies in pilot training: The anatomy of transfer.* ARL Aviation Research Monographs, 1972, 2(1), 1-87. TRAINING.
- FLEXMAN, R.E., TOWNSEND, J.C. and ORNSTEIN, G.N. *Evaluation of a contact flight simulator when used in a USAF Primary Pilot Training Programme Part 1 - Overall effectiveness.* AFPTRC TR-54-38, 1954. TRAINING.
- FRANCIS, B.C. *Display systems for VTO transport aircraft.* IEE Conference Publication No. 80, 1971, 301-305. CONTROLS and DISPLAYS.
- FRASIER, J.W., WHITNEY, R.U., ASHARE, A.B., ROGERS, D.B. and SKOWRONSKI, V.D. *G-suit filling pressures determined by seat-back angle.* Aerospace Medicine, 1974, 45, 755-757. HUMAN PERFORMANCE.
- FRICK, R.K. *Quantitative effects in the use of simulators for training fighter pilots.* AIAA 72-161, 1972. TRAINING.
- FRISBY, C.B. *Field research in flying training.* Occupational Psychology, 1947, 21, 24-33. TRAINING.
- FULGAM, D.D., REID, G.B., WOOD, M.E. and McLEOD, I.N. *Design and application of a part-task trainer to teach formation flying in the USAF Undergraduate Pilot Training.* AIAA 73-935, 1973. TRAINING.
- GABRIEL, R.F. and BURROWS, A.A. *Improving time-sharing performance of pilots through training.* Human Factors, 1968, 10, 33-40. TRAINING.
- GABRIEL, R.F., BURROWS, A.A. and ABBOTT, P.E. *Using a generalised contact flight simulator to improve visual time-sharing.* NTDC 1428-1, April 1965. VISUAL CUES.
- GAGNE, R.M. *Training devices and simulators: Some research issues.* American Psychologist, 1954, 9, 95-107. GENERAL and THEORETICAL.
- GAINER, C.A. and OBERMEYER, R.W. *Pilot eye fixations while flying selected manoeuvres using two instrument panels.* Human Factors, 1964, 6, 485-501. CONTROLS and DISPLAYS.
- GALLAGHER, J.T. *Simulation and analysis in establishing flying qualities criteria.* AGARD CP-106, 1971. AIRCRAFT HANDLING.
- GALLAGHER, J.T. and NELSON, W. *Use of simulators in the design and development of flight control systems.* SAE 730933, 1973. CONTROLS and DISPLAYS.
- GEISELHART, R., JARBOE, J.K. and KEMMERLING, P.T. *Investigation of pilot's tracking capability using a roll command display.* ASD TR-71-46, 1971. CONTROLS and DISPLAYS.

- GEISELHART, R., KEMMERLING, P., CRONBURG, J.G. and THORBURN, D.E. *A comparison of pilot performance using a centre stick versus sidearm control configuration.* ASD TR-70-39, 1970. CONTROLS and DISPLAYS.
- GERATHEWOHL, S.J. *Fidelity of simulation and transfer of training: A review of the problem.* FAA AM-69-24, 1969. TRAINING.
- GERDES, R.M. and WEICK, R.F. *A preliminary piloted simulator and flight study of height control requirements for VTOL aircraft.* NASA TN-1201, 1962. CONTROLS and DISPLAYS.
- GERKEN, G.J. and STONE, J.R. *Piloted power-approach simulation.* Proceedings of Fourth Annual Symposium of the Society of Flight Test Engineers, Las Vegas, Nevada, U.S.A., August 1973. AIRCRAFT HANDLING.
- GERLACH, O.H., BRAY, R.S., COVELLI, D., CZINCZENHEIM, J., HAAS, R.L., LEAN, D., SCHMIDTLEIN, H. and WASICKO, R.J. *Approach and landing simulation.* AGARD R-632, 1975. GENERAL and THEORETICAL.
- GIBINO, D.J. *Effects of presence or absence of cockpit motion in IF trainers and flight simulators.* ASD TR-68-24, 1968a. MOTION CUES.
- GIBINO, D.J. *A systems analysis approach to the design of aircrew training equipment.* AIAA 68-274, 1968b. TRAINING.
- GIBSON, J.H. *Optimised flight crew training - a step toward safer operations.* AIAA 69-771, 1969. TRAINING.
- von GIERKE, H.E. and STEINMETZ, E. *Motion devices for linear and angular oscillation and for abrupt acceleration studies on human subjects (impact).* National Academy of Sciences, National Research Council, Washington DC, U.S.A. Publication 903, 1961. MOTION CUES.
- GILLMAN, R.E. *In defence of simulators.* Flight International, 1969, 96, 93-94. GENERAL and THEORETICAL.
- GOLD, T. *Flight simulation study of head-up displays for high-speed flight at low altitudes.* Proceedings of IEEE-GMMS ERS International Symposium 'Man-Machine Systems', Cambridge, England, September 1969. CONTROLS and DISPLAYS.
- GOLD, T. *Visual perception of pilots in carrier landing.* AIAA 73-917, 1973. HUMAN PERFORMANCE.
- GOLD, R.E. and KULAK, L.L. *Effect of hypoxia on aircraft pilot performance.* Aerospace Medicine, 1972, 43, 180-183. HUMAN PERFORMANCE.
- GOODIER, J.H. *Tools for the flight simulator instructor.* Proceedings of R.Ae.S. Symposium 'Flight Training Simulators for the 70s', London, England, October 1970. GENERAL and THEORETICAL.
- GRAHAM, D.K. *A rationale for moving-base flight simulation and a preliminary statement of the motion requirements.* The Boeing Corporation, Seattle, Washington DC, U.S.A. D6-57149, 1968. MOTION CUES.
- GRAHAM, W. and MANGULIS, V. *Results of a visual detection simulation experiment for the evaluation of Aircraft Pilot Warning Instruments (APWI).* Final Report. AD A-017023/3, 1974. CONTROLS and DISPLAYS.
- GRAHAM, W., REED, J. and MEYER, E. *A visual detection simulator for pilot warning instrument evaluation.* AIAA 73-916, 1973. VISUAL CUES.
- GRANTHAM, W.D. and DEAL, P.L. *A piloted fixed-base simulator study of low-speed flight characteristics of an arrow-wing supersonic transport design.* NASA TN-D-4277, 1968. AIRCRAFT HANDLING.
- GRANTHAM, W.D. and DEAL, P.L. *Simulator study of minimum acceptable level of longitudinal stability for a STOL configuration during landing approach.* NASA TN-D-7733, 1974. AIRCRAFT HANDLING.
- GRANTHAM, W.D., NGUYEN, L.T. and DEAL, P.L. *Simulation of decelerating landing approaches on an externally blown flap STOL transport airplane.* NASA TN-D-7463, 1974. AIRCRAFT HANDLING.
- GRANTHAM, W.D., NGUYEN, L.T., PATTON, J.M., DEAL, P.L., CHAMPINE, R.A. and CARTER, C.R. *Fixed-base simulator study of an externally blown flap STOL transport airplane during approach and landing.* NASA TN-D-6898, 1972. AIRCRAFT HANDLING.
- GRANTHAM, W.D., SOMMER, R.W. and DEAL, P.L. *Simulator study of flight characteristics of a jet-flap STOL transport airplane during approach and landing.* NASA TN-D-6225, 1971. AIRCRAFT HANDLING.

GREENING, C.P. and WYMAN, M.J. *Experimental evaluation of a visual detection model*. Human Factors, 1970, 12, 435-445. HUMAN PERFORMANCE.

GRIFFITHS, W.E.B. *A review of the current policy in the UK for the use of flight simulators in flight crew training and checking*. SAE 670311, 1971. GENERAL and THEORETICAL.

GUERCIO, J.G. and WALL, R.L. *Congruent and spurious motion in the learning and performance of a compensatory tracking task*. Human Factors, 1972, 14, 229-236. MOTION CUES.

GUM, D.R. and ALBERY, W.B. *Integration of an advanced CIG visual and simulator system*. Proceedings of AIAA Visual and Motion Simulation Conference, Dayton, Ohio, U.S.A., April 1976. MOTION CUES.

GUNDRY, A.J. *The role of motion in flight simulator training: An alternative interpretation of some recent evidence*. IAM S-123, March 1975. MOTION CUES.

GUNDRY, A.J. *Man and motion cues*. Proceedings of R.Ae.S. Symposium 'Theory and Practice in Flight Simulation', London, England, April 1976a. MOTION CUES.

GUNDRY, A.J. *Thresholds to roll motion in a flight simulator*. Proceedings of AIAA Visual and Motion Simulation Conference, Dayton, Ohio, U.S.A., (loose paper), April 1976b. MOTION CUES.

HASS, W.-D. *A study of the cost benefits of using flight simulators for crew training*. DGLR Anthropotechnicians Committee, 16th Meeting, Frankfurt, Germany, November 1974. (In German). TRAINING.

HALE, H.B., GARCIA, J.B., ELLIS, J.P. and STORM, W.F. *Human amino acid secretion patterns during and following prolonged multistressor tests*. Aviation, Space and Environmental Medicine, 1975, 46, 173-178. HUMAN PERFORMANCE.

HALL, E.R. and CARO, P.W. *Systems engineering of Coast Guard Aviator training*. HumRRO PP-17-71, 1971. TRAINING.

HALL, E.R., PARKER, J.F. and MEYER, D.E. *A study of Air Force flight simulator programmes*. AMRL TR-67-111, 1967. GENERAL and THEORETICAL.

HAMILTON, J.E. *F-101/F-106 flight simulator flashblindness experiment*. SAM TR-65-82, 1965. HUMAN PERFORMANCE.

HAMMERTON, M. *Measures for the efficiency of simulators used as training devices*. Ergonomics, 1967, 10(1), 63-65. GENERAL and THEORETICAL.

HARDY, J.D. and CLARK, C.C. *The development of dynamic flight simulation*. NADC-1 (AD 216 508), 1958. MOTION CUES.

HARPER, C.R. and KIDERA, G.J. *Aviator performance and the use of hypnotic drugs*. Aerospace Medicine, 1972, 43, 197-199. HUMAN PERFORMANCE.

HARPER, C.R., KIDERA, G.J. and CULLEN, J.F. *A study of simulated airline pilot incapacitation*. Proceedings of Eighteenth International Congress 'Aerospace Medicine', Amsterdam, Netherlands, September 1969. HUMAN PERFORMANCE.

HARRIS, R.L. and HEWES, D.E. *An exploratory simulation study of a HUD for general aviation light planes*. NASA TN D-7456, 1973. CONTROLS and DISPLAYS.

HARTMAN, B.O. and SIMONS, D.G. *Fatigue effects in 24 hour simulated transport flight: Changes in pilot proficiency*. Aerospace Medical Association, 34th Annual Scientific Meeting, Los Angeles, California, U.S.A., May 1963. HUMAN PERFORMANCE.

HASBROOK, A.H. *A comparison of effects of peripheral vision cues on pilot performance during instrument flight in dissimilar aircraft simulators*. FAA AM-68-22, 1968. CONTROLS and DISPLAYS.

HASBROOK, A.H. and YOUNG, P.E. *Pilot response to peripheral vision cues during instrument flying tasks*. FAA AM-68-11. 1968a. CONTROLS and DISPLAYS.

HASBROOK, A.H. and YOUNG, P.E. *Peripheral vision cues: Their effect on pilot performance during IL approaches and recoveries from unusual attitudes.* FAA AM-68-12, 1968b. CONTROLS and DISPLAYS.

HAAS, D. and VOLK, W. *Status and development trends of simulation technology -- It's effects on the training of airline pilots.* Deutsche Gesellschaft fur Ortung und Navigation, Nationale Tagung uber Simulation im Dienste des Verkehrs, Bremen, W. Germany. Paper 3.4, 1975. (In German). GENERAL and THEORETICAL.

HATTESTAD, B. and RIIS, E. *Measurement of performance in F-86 simulator.* Royal Norwegian Air Force Psychological Services of the Armed Forces, Oslo, Norway. 1967. HUMAN PERFORMANCE.

HAVRON, M.D. and BUTLER, L.F. *Evaluation of training effectiveness of the 2-FH-2 helicopter flight trainer research tool.* NTDC 1915-00-1, 1957. TRAINING.

HAXTHAUSEN, B. *Flight training: Toward the zero hour.* Airline Management, May 1972. GENERAL and THEORETICAL.

HEFFLEY, R.K., JEWELL, W.F., STAPLEFORD, R.L., CRAIG, S.J., HYNES, C.S. and SCOTT, B.C. *A STOL airworthiness investigation using a simulation of a deflected slipstream transport. Vol. 3: Breguet 941S simulation model.* NASA TM-X-62394, 1974. AIRCRAFT HANDLING.

HENRY, P.H. *Subject instruction manual for the pilot performance evaluation system.* Final Report, March 1971-April 1974. SAM TR-74-40, 1974. GENERAL and THEORETICAL.

HENRY, P.H., DAVIS, T.Q., ENGELKEN, E.J., TRIEBWASSER, J.H. and LANCASTER, M.C. *Alcohol-induced performance decrements assessed by two Link trainer tasks using experienced pilots.* Aerospace Medicine, 1974, 45, 1180-1189. HUMAN PERFORMANCE.

HENRY, P.H., FLUECK, J.A., SANFORD, J.F., KEISER, H.N., McNEE, R.C., WALTER, W.H., WEBSTER, K.H., HARTMAN, B.O. and LANCASTER, M.C. *Assessment of performance in a Link GAT-1 flight simulator at three alcohol dose levels.* Aerospace Medicine, 1974, 45, 33-44. HUMAN PERFORMANCE.

HENRY, P.H., TURNER, R.A. and MATTHIE, R.B. *An automated system to assess pilot performance in a Link GAT-1 trainer.* Final Report, March 1971-May 1973. SAM TR-74-41, 1974. HUMAN PERFORMANCE.

HILL, J.W. and GOEBEL, R.A. *Development of automated GAT-1 performance measures.* AFHRL TR-71-18, 1971. HUMAN PERFORMANCE.

HOLZHAUSER, C.A., INNIS, R.C. and VOMASKE, R.F. *A flight and simulator study of the handling qualities of a deflected slipstream STOL seaplane having four propellers and boundary layer control.* NASA TN-D-2966, 1965. AIRCRAFT HANDLING.

HOPKIN, V.D. and NAPIER, A.W. *Time estimation in a flight simulator.* IAM R-232, 1963. HUMAN PERFORMANCE.

HOPKIN, V.D., POULTER, R.F. and WHITESIDE, T.C.D. *Effects of a blinded retinal area on performance of a simulated flight task.* IAM R-449, 1968. CONTROLS and DISPLAYS.

HOPKINS, C.O. *How much should you pay for that box?* Human Factors Society 18th Annual Meeting, Huntsville, Alabama, U.S.A., October 1974. GENERAL and THEORETICAL.

HOWELL, J.D. *Simulator evaluation of pilot assurance derived from an airborne traffic situation display.* FAA EM-72-3, 1972. CONTROLS and DISPLAYS.

HUDDLESTON, H.F. *HUD evaluation by limited flight simulation. Phase 2: Comparison of two targets, four markers and four director tracks.* IAM R-285, 1964a. CONTROLS and DISPLAYS.

HUDDLESTON, H.F. *Head-up display evaluation by limited flight simulation. Phase 3: Three range scales and the director track.* IAM R-304, 1964b. CONTROLS and DISPLAYS.

HUDDLESTON, H.F. *Cockpit motion requirements for flight simulation.* IAM R-363, 1966. MOTION CUES.

HUDDLESTON, H.F. and NAPIER, A.W. *Measuring pilot performance and control in a flight task simulator.* IAM T-226, 1964. HUMAN PERFORMANCE.

HUDDLESTON, H.F., NAPIER, A.W., POULTER, R.F. and SAMUEL, G.D. *Learning to track with an acceleration control in a simulated flying task.* IAM R-383, 1969. HUMAN PERFORMANCE.

HUDDLESTON, H.F., NAPIER, A.W. and ROLFE, J.M. *Pilot familiarisation behaviour in a flight test simulator*. IAM R-331, 1965. HUMAN PERFORMANCE.

HUDDLESTON, H.F. and ROLFE, J.M. *Behavioural factors influencing aircrew response in training and research simulators*. Proceedings of R.Ae.S. Symposium 'Flight Training Simulators for the 70s', London, England, October 1970. GENERAL and THEORETICAL.

HUDDLESTON, H.F. and SAMUEL, G.D. *HUD evaluation by limited flight simulation. Phase 1: Comparison of two targets and two aircraft marker symbols*. IAM R-261, 1963. CONTROLS and DISPLAYS.

HUDDLESTON, H.F. and WILSON, R.V. *An evaluation of the usefulness of four secondary tasks in assessing the effect of a lag in simulated aircraft dynamics*. Ergonomics, 1971, 14, 371-380. CONTROLS and DISPLAYS.

HUFF, E.M. and NAGEL, D.C. *Psychological aspects of aeronautical flight simulation*. American Psychologist, 1975, 30(3), 406-439. GENERAL and THEORETICAL.

HULL, R.E. *Navigator training analysis*. Institute of Navigation 25th Anniversary Year Meeting, U.S. Academy, Colorado Springs, Colorado, U.S.A., July 1970. TRAINING.

HURT, G.J. *Rough air effect on crew performance during a simulated low-altitude high-speed surveillance mission*. NASA TN-D-1924, 1963. HUMAN PERFORMANCE.

IAMPIETRO, P.F., MELTON, C.E., HIGGINS, E.A., VAUGHAN, J.A., HOFFMAN, S.M., FUNKHOUSER, G.E. and SALDIVAR, J.T. *High temperature and performance in a flight task simulator*. FAA AM-72-7, 1972. HUMAN PERFORMANCE.

INCE, F., WILLIGES, R.C. and ROSCOE, S.N. *Aircraft simulator motion and the order of merit of flight attitude and steering guidance displays*. Human Factors, 1975, 17, 388-400. CONTROLS and DISPLAYS.

ISLEY, R.N., CARO, P.W. and JOLLEY, O.B. *Evaluation of synthetic instrument flight training in the Officer/Warrant Officer Rotary Wing Aviator Course*. HumRRO TR-68-14, 1968. TRAINING.

JACOBS, R.S. and ROSCOE, S.N. *Simulator cockpit motion and the transfer of initial flight training*. ARL-75-18/AFOSR-75-8, 1975. MOTION CUES.

JACOBS, R.S., WILLIGES, R.C. and ROSCOE, S.N. *Simulator motion as a factor in flight director display evaluation*. Human Factors, 1973, 15, 569-582. CONTROLS and DISPLAYS.

JACOBSEN, R.A. and GRIEF, R.K. *Simulation study of the lift-roll coupling problem for hovering VTOL aircraft*. NASA TN-D-6906, 1972. AIRCRAFT HANDLING.

JACOBSON, D., SCHOULTZ, M.B. and BLAKE, J.C. *Effect of motion frequency spectrum on subjective comfort response*. NASA CR-138883, 1973. MOTION CUES.

JANOWSKY, D.S., MEACHAM, M.P., BLAINE, J.D., SCHOOR, M. and BOZZETTI, L.P. *Simulated flying performance after marijuana intoxication*. Aviation, Space and Environmental Medicine, 1976, 47, 124-128. HUMAN PERFORMANCE.

JEFFS, E. *Flight simulators gain in realism*. Design Engineering, 1970, September 15, 47-50. GENERAL and THEORETICAL.

JENKINS, M.W.M. and HACKETT, J.E. *A pilot-in-the-loop visual simulation of trailing vortex encounters at low speed*. AIAA 75-104, 1975. AIRCRAFT HANDLING.

JOHNSON, J.H. *An evaluation of a device designed to teach the principles of trimming an aircraft*. Naval Aviation Medical Centre, Pensacola, Florida, U.S.A. Special Report No. 61-1, 1961. TRAINING.

JOHNSON, S.L., WILLIGES, R.C. and ROSCOE, S.N. *A new approach to motion relations for flight director displays*. ARL 71-20, 1971. CONTROLS and DISPLAYS.

- JOHNSON, W.A. and CRAIG, S.J. *Configuration management during transition for a powered-lift STOL aircraft*. AIAA 74-836, 1974. AIRCRAFT HANDLING.
- JOHNSON, W.A., CRAIG, S.J. and ASKENAS, I.L. *Analysis and moving-base simulation of transition configuration management aspects of a powered-lift aircraft*. NASA CR-114698, 1973. AIRCRAFT HANDLING.
- JOHNSON, W.J. *Flight simulation and airline pilot training*. IAM R-442, Paper 1, 1968. GENERAL and THEORETICAL.
- JOHNSON, W.J. *Desirable improvements in future airline flight simulators and associated training equipment*. Proceedings of R.Ae.S. Symposium 'Flight Training Simulators for the 70s', London, England, October 1970. GENERAL and THEORETICAL.
- JOHNSTON, D.E. and HOGGE, J.R. *The effect of non-symmetric flight on aircraft high angle of attack handling qualities and departure characteristics*. AIAA 74-792, 1974. AIRCRAFT HANDLING.
- JOLLEY, O.B. and CARO, P.W. *A determination of selected costs of flight and synthetic flight training*. HumRRO TR-70-6, 1970. TRAINING.
- JONES, J.G. and TOMLINSON, B.N. *The representation of low altitude atmospheric turbulence in piloted ground-based simulators*. RAE TR-71198, 1971. AIRCRAFT HANDLING.
- JUNKER, A.M. and PRICE, D. *Comparison between a peripheral display and motion information on human tracking about the roll axis*. Proceedings of AIAA Visual and Motion Simulation Conference, Dayton, Ohio, U.S.A., April 1976. MOTION CUES.
- JUNKER, A.M. and REPLOGLE, C.R. *Motion effects on the human operator in a roll axis tracking task*. Aviation, Space and Environmental Medicine, 1975, 46(6), 819-822. MOTION CUES.
- KAESTNER, R. *On the effect of reliability of simulation results on the methodology of flight testing and simulation*. NASA TT-F-15175, 1973. AIRCRAFT HANDLING.
- KARIM, B., BERGEY, K.H., CHANDLER, R.F., HASBROOK, A.H., PURSWELL, J.L. and SNOO, C.C. *A preliminary study of maximal control force capability of female pilots*. FAA AM-72-27, 1972. CONTROLS and DISPLAYS.
- KATZ, S., ASE, P.K., RAISEN, E. and HILDENDORF, R.L. *Visual performance with simulated flaresight in artificial clouds*. Final Report. February–August 1969. AMRL TR-69-121, 1969. HUMAN PERFORMANCE.
- KEEGAN, J.B. *The design of simulators as aids to instruction*. Proceedings of R.Ae.S. Symposium 'Theory and Practice in Flight Simulation', London, England, April 1976. GENERAL and THEORETICAL.
- KELLEY, C.R., BOWEN, H.M., ELY, J.H. and ANDREASSI, J.L. *Tracking training III: Transfer of training*. NTDC 1908-00-3, January 1960. TRAINING.
- KELLEY, C.R., de GROOT, S. and BOWEN, H.M. *Relative motion II: Some relative motion problems in aviation*. NTDC 316-2, January 1961. CONTROLS and DISPLAYS.
- KESLER, D.F., MURAKOSHI, A.Y. and SINACORI, J.B. *Flight simulation of the Model 347 advanced tandem-rotor helicopter*. Final Report, July 1972–October 1973. U.S. Army Air Mobility R & D Laboratories, Fort Eustis, Virginia, U.S.A. AAMRDL TR-74-21, 1974. AIRCRAFT HANDLING.
- KINGDON, R.L. *Concept of operations for a full mission fighter simulator (FMFS)*. AD-785901, 1974. TRAINING.
- KIRKPATRICK, M. and BRYE, R.G. *Man-machine evaluation of moving-base vehicle simulation motion cues*. NASA CR-120706, 1974. MOTION CUES.
- KLEIN, K.E., BRUNER, H., HOLTMANN, H., REHME, H., STOLZE, J., STEINHOFF, W.D. and WEGMANN, H.M. *Circadian rhythms of pilots' performance in a flight simulator and effects of time shift*. AGARD CP-61-70, 1970. HUMAN PERFORMANCE.
- KNOOP, P.A. *Advanced instructional provisions and automated performance measurement*. Human Factors, 1973, 15, 583-597. TRAINING.

KNOWLES, W.B. *Aerospace simulation and human performance research*. Human Factors, 1967, 9(2), 149-159. GENERAL and THEORETICAL.

KOONCE, J.M. *Effects of ground-based aircraft simulator motion conditions upon prediction of pilot proficiency*. ARL 74-5/AFOSR 74-3 Parts 1 & 2, 1974. MOTION CUES.

KRAFT, C.L. and ELWORTH, C. *Night visual approaches in air transportation*. Proceedings of IEEE-GMMS ERS International Symposium 'Man-Machine Systems', Cambridge, England, September 1969. AIRCRAFT HANDLING.

KRAUS, E.F. *A parametric study of pilot performance with modified aircraft control dynamics, varying navigational task complexity, and induced stress*. ARL 73-10/AFOSR 73-6/FAA 73-3, 1973. HUMAN PERFORMANCE.

KREIFELDT, J.G. and WEMPE, T. *Pilot performance during a simulated standard instrument procedure turn with and without a predictor display*. Proceedings of 9th Annual Manual Control Conference, Massachusetts Institute of Technology, Massachusetts, U.S.A., 1973, 147-162. CONTROLS and DISPLAYS.

KRENDEL, E.S. and BLOOM, J.S. *The natural pilot model for flight proficiency evaluation*. NTDC 323-1, 1963. HUMAN PERFORMANCE.

KURKOWSKI, R.L., FICHTL, G.H. and GERA, J. *Development of turbulence and wind-shear models for simulator application*. NASA SP-270, 1971. AIRCRAFT HANDLING.

LAMONT, J.N. *Annotated bibliography on flight simulators*. Directorate of Biosciences Research, Defence Research Board, Ottawa, Canada. Technical Report HR68 (AD 247 044), August 1960. GENERAL and THEORETICAL.

LANIER, H.M. and BUTLER, E.D. *An experimental assessment of a ground trainer in general aviation*. FAA ADS-64, 1966. TRAINING.

LARSON, D.F. and TERRY, C. *Advanced Simulation in Undergraduate Pilot Training (ASUPT): Systems integration*. AFHRL TR-75-59-7, 1975. VISUAL CUES.

LAYTON, D.M. *A simulator evaluation of pilot performance and acceptance of an aircraft rigid cockpit control system*. Naval Postgraduate School, Monterey, California, U.S.A. Paper 57 LN 70071A, 1970. CONTROLS and DISPLAYS.

LEEPER, R.C., HASBROOK, H.A. and PURSWELL, J.L. *Study of control force limits for female pilots*. FAA AM-73-23, 1973. CONTROLS and DISPLAYS.

LEMONS, J.L. and DUKES, T.A. *A simulator study on information requirements for precision hovering*. NASA TM-X-62464, 1975. CONTROLS and DISPLAYS.

LEWIS, O.W. *Simulation -- the new approach*. Air University Review, Mar-Apr 1974, 25, 41-55. GENERAL and THEORETICAL.

LLOYD, D.A., LEGG, R.C.F. and WILLIAMS, E.M. *MOD flight simulator at Smiths Industries Ltd. Task 5. Assessment of the effects of height resolution in a head-up display*. Smiths Industries Ltd, Aviation Division, Bishops Cleeve, Cheltenham, England. Report RID 1302, November 1971. CONTROLS and DISPLAYS.

LOWES, A.L., ELLIS, N.C., NORMAN, D.A. and MATHENY, W.G. *Improving piloting skills in turbulent air using a self-adaptive technique for a digital Operational Flight Trainer (OFT)*. NTDC 67-C-0034-2, August 1968. TRAINING.

LUCE, L. *Vital II*. Shell Aviation News, 1973, 419, 26-29. VISUAL CUES.

LYBRAND, W.A., HAVRON, M.D., GARTNER, W.B., SCARR, H.A. and HACKMAN, R.C. *Simulation of extra-cockpit visual cues in contact flight transition trainers*. AFPTRC TR-58-11, 1958a. VISUAL CUES.

LYBRAND, W.A., HAVRON, M.D., GARTNER, W.B., SCARR, H.A. and HACKMAN, R.C. *Simulation of extra-cockpit visual cues in contact flight transition trainers*. AFPTRC TR-58-11, APPENDIX I, 1958b. VISUAL CUES.

MAHLER, W.R. and BENNETT, G.K. *Special devices in primary flight training: Their training and selection value*. SDC 151-1-18, 1949. TRAINING.

MAHLER, W.R. and BENNETT, G.K. *Psychological studies of advanced naval air training: Evaluation of Operational Flight Trainers (OFTs)*. SDC 999-1-1, 1950a. TRAINING.

MAHLER, W.R. and BENNETT, G.K. *Psychological studies of advanced naval air training: Analysis of flight performance ratings*. SDC 999-1-2, 1950b. TRAINING.

MAIORIELLO, R.P. *Effects of pyrobenzamine and plimasin on fighter pilots flying a fighter intercept mission in the F4D flight simulator*. Aviation, Space and Environmental Medicine, 1975, 46, 1191-1193. HUMAN PERFORMANCE.

MARR, R.L. and RODERICK, W.E.B. *Handling qualities evaluation of the X-15 tilt rotor aircraft*. AHS Preprint 840, May 1974. AIRCRAFT HANDLING.

MATHENY, W.G. *Training simulator characteristics: Research problems, methods and performance measurements*. Proceedings of a conference convened at US Army Aviation Centre, Fort Rucker, Alabama, U.S.A., November 1973, 137-148. TRAINING.

MATHENY, W.G., DOUGHERTY, D.J. and WILLIS, J.M. *Relative motion of elements in instrument displays*. Aerospace Medicine, 1963, 34, 1031-1046. CONTROLS and DISPLAYS.

MATHENY, W.G., LOWES, A.L. and BYNUM, J.A. *An experimental investigation of the role of motion in ground-based trainers*. Final Report. Dec 1970-June 1973. NAVTRAEQUIPCEN 71-C-0075-1, 1974. MOTION CUES.

MATHENY, W.G., WILLIAMS, A.C., DOUGHERTY, D. and HASLER, S.G. *The effect of varying control forces in the P-1 trainer upon transfer of training to the T-6 aircraft*. HumRRO 53-31, 1953. CONTROLS and DISPLAYS.

MATTHEWS, N.O. *The relative importance of physiological and visual factors in providing realism in flight simulation*. Proceedings of R.Ae.S. Symposium 'Flight Training Simulators for the 70s', London, England, October 1970. VISUAL CUES.

MATTHEWS, N.O. *Helicopter flight simulators*. Aircraft Engineering, Feb, 1976, 48, 17-20. VISUAL CUES.

McCLURE, R.D. and KOTTMANN, H.A. *Parallelism in commercial airline and military use of simulation*. AIAA 75-971, 1975. GENERAL and THEORETICAL.

McCULLOCH, G. *How United trains DC-10 pilots*. Shell Aviation News, 1972, 408, 2-6. TRAINING.

McGRATH, J.J., OSTERHOFF, W.E., SELTZER, M.L. and BORDEN, G.J. *Geographic orientation in aircraft pilots: Methodological advancement*. Human Factors Research Inc., Goleta, California, U.S.A. Report 751-5, 1965. VISUAL CUES.

McGREGOR, D.M. *Some factors influencing the choice of a simulator*. AGARD CP-79-70, 1971. GENERAL and THEORETICAL.

McGUINNESS, J., DRENNEN, T.G. and CURTIN, J.G. *Manual control in target tracking tasks as a function of controller characteristics: A flight simulator investigation. Phase 2*. McDonnell-Douglas Corporation, Douglas Aircraft Co., 3855 Lakewood Blvd., Long Beach, California 90801, U.S.A. MDC E-1148, 1974. CONTROLS and DISPLAYS.

McLANE, R.C. and WIERWILLE, W.W. *The influence of motion and audio cues on driver performance in an automobile simulator*. Human Factors, 1975, 17, 486-501. MOTION CUES.

McLAUGHLIN, M.D. and WHITTEN, J.B. *Pilot evaluation of dynamic stability characteristics of a supersonic transport in cruising flight using a fixed-base simulator*. NASA TN-D-2436, 1964. AIRCRAFT HANDLING.

MELANSON, D. *Simulator evaluation of pilot assurance derived from an Airborne Traffic Situation Display (ATSD). Phase 2: Traffic awareness improvement*. Final Project Report. 1 March 1972-30 June 1973. FAA EM-74-10, 1974. CONTROLS and DISPLAYS.

MELTON, C.E., MCKENZIE, J.M., KELLN, J.R., HOFFMAN, M. and SALDIVAR, J.T. *Effect of a general aviation trainer on the stress of flight training*. Aviation, Space & Environmental Medicine, 1975, 46, 1-5. TRAINING.

MENDELA, D.K. *Simulator investigation of the VTOL transport*. Journal of Aircraft, 1971, 8(10), 783-789. AIRCRAFT HANDLING.

MENGELKOCH, R.F. *Pilot simulator performance with two flight instrument panels*. The Martin Company, Baltimore, Maryland, U.S.A. ER-10846, 1961. CONTROLS and DISPLAYS.

MENGELKOCH, R.F., ADAMS, J.A. and GAINER, C.A. *The forgetting of instrument flying skills*. Human Factors, 1971, 13, 397-405. TRAINING.

MESHER, C.W. *Air combat manoeuvring training in a simulator*. Proceedings of AGARD FMP/GCP Symposium 'Flight Simulation/Guidance Systems Simulation', The Hague, Netherlands, October 1975. TRAINING.

MEYER, D.E., FLEXMAN, R.E., van GUNDY, E.A., KILLIAN, D.C. and LANAHAN, C.J. *A study of simulator capabilities in an operational training programme*. AMRL TR-67-14, May 1967. TRAINING.

MICHLIK, M.J. *A visual landing simulator for a ground-based trainer*. AD 732 323, 1971. VISUAL CUES.

MIDDLETON, D.B. and BERGERON, H.P. *A compilation and analysis of typical approach and landing data for a simulator study of an externally blown flap STOL aircraft*. NASA TN-D-7497, 1974. AIRCRAFT HANDLING.

MIDDLETON, D.B., HURT, G.J., BERGERON, H.P., PATTON, J.M., DEAL, P.L. and CHAMPINE, R.A. *Motion-base simulator study of control of an externally blown flap STOL transport aircraft after failure of an outboard engine during landing approach*. NASA TN-D-8026, 1975. AIRCRAFT HANDLING.

MILLER, G.E. *New longitudinal handling qualities data - carrier approaches*. AIAA 69-897, 1969. AIRCRAFT HANDLING.

MILLER, G.G. *Some considerations in the design and utilisation of simulators for technical training*. AFHRL TR-74-65, 1974, GENERAL and THEORETICAL.

MILLER, G.K. *A motion-constraint logic for moving-base simulators based on variable filter parameters*. NASA TN-D-7777, 1974. MOTION CUES.

MILLER, G.K. and DEAL, P.L. *Moving-base visual simulation study of decoupled controls during approach and landing of a STOL transport aircraft*. NASA TN-D-7790, 1975. AIRCRAFT HANDLING.

MILLER, G.K., DEAL, P.L. and CHAMPINE, R.A. *Fixed-base simulation study of decoupled controls during approach and landing of a STOL transport airplane*. NASA TN-D-7363, 1974. AIRCRAFT HANDLING.

MILLER, G.K. and RILEY, D.R. *The effect of visual-motion time delays on pilot performance in a pursuit tracking task*. Proceedings of AIAA Visual and Motion Simulation Conference, Dayton, Ohio, U.S.A., April 1976. MOTION CUES.

MILLER, J.W. and GOODSON, J.E. *A note concerning "motion sickness" in the 2-FH-2 hover trainer*. U.S. Naval School of Aviation Medicine, U.S. Naval Station, Pensacola, Florida, U.S.A. Research Project NM 17 01 11 Subtask 3 Report 1, February 1958. VISUAL CUES.

MILLER, R.B. *Task and part-task trainers and training*. WADC TR-60-469, 1960. TRAINING.

MOEN, G.C. and YENNI, K.R. *Simulation and flight studies of an approach profile indicator for VTOL aircraft*. NASA TN-D-8051, 1975. CONTROLS and DISPLAYS.

MOLNAR, A.R. and LYBRAND, W.A. *Basic development accomplished on wide-angle, non-programmed visual presentation*. Vol. I, Vol. II, Appendix. NASA 404 (2 Vols.) 1959. VISUAL CUES.

MONTEITH, W. and LEGG, R.C.F. *MOD flight simulator at Smith Industries Ltd. Task 4. An investigation of some aspects of an integrated vertical situation display, including the factors affecting the choice of the roll resolving point and the importance of including an indication of sideslip on the display*. Smiths Industries Ltd., Aviation Division, Bishops Cleeve, Cheltenham, England. Report RID 1301, December 1971. CONTROLS and DISPLAYS.

MOORHOUSE, D.J. and JENKINS, M.W.M. *A statistical analysis of pilot control during a simulation of STOL landing approaches*. AIAA 73-182, 1973. HUMAN PERFORMANCE.

MORAN, W.P. *The use of simulation to promote safety and economy in flying training*. IATA DOC/GEN 2306, 1971a. TRAINING.

MORAN, W.P. *Simulation - the only safe way*. 24th Flight Safety Foundation Annual International Air Safety Seminar, Mexico City, Mexico, October 1971b. TRAINING.

MORAN, W.P. *Total simulation - a near future goal*. Proceedings of R.Ae.S. Second Flight Simulation Symposium, London, England, May 1973. GENERAL and THEORETICAL.

MORRIS, E. and MATTHEWS, N.O. *New visual and motion techniques in military flight simulation*. Proceedings of R.Ae.S. Symposium 'Theory and Practice in Flight Simulation', London, England, April 1976. VISUAL CUES.

MUCKLER, F.A., NYGAARD, J.E., O'KELLY, L.I. and WILLIAMS, A.C. *Psychological variables in the design of flight simulators for training*. WADC TR-56-369, January 1959. TRAINING.

MUDD, S. *Assessment of the fidelity of dynamic flight simulators*. Human Factors, 1968, 10, 351-358. GENERAL and THEORETICAL.

MURPHY, M.R. and GREIF, R.K. *Simulation evaluation of a perspective clipped-pole display and a thrust-vector controller for VTOL zero-zero landings*. NASA TM-X-62464, 1975. CONTROLS and DISPLAYS.

NAISH, J.M. *Simulation of visual flight with particular reference to the study of flight instruments*. RAE TN-IAP-1099, August 1959. VISUAL CUES.

NAVE, R.L. *A pilot/LSO simulation conducted to investigate aircraft wave-off performance and to determine the ability of the landing signal officer to judge aircraft approaches*. Final Report. NASA 74112-30, 1974. AIRCRAFT HANDLING.

NEWELL, F.D. *Criteria for acceptable representation of airplane dynamic responses in simulators used for pilot training*. NTDC 1146-1, October 1962. TRAINING.

NEWELL, F.D. *Ground simulator evaluations of coupled roll-spiral mode effects on aircraft handling qualities*. Cornell Aeronautical Laboratories Inc., Buffalo, New York, U.S.A. Report TC 1921-F-1, March 1965. AIRCRAFT HANDLING.

NEWELL, F.D. and SMITH, H.J. *Human transfer characteristics in flight and ground simulation for a roll tracking task*. NASA TN-D-5007, 1969. MOTION CUES.

NICHOLL, J. *The economics of the ultimate simulator*. Proceedings of R.Ae.S. Symposium 'Flight Training Simulators for the 70s', London, England, October 1970. GENERAL and THEORETICAL.

NIEUWENHUIJSE, A.W. and FRANKLIN, J.A. *A simulator investigation of engine failure compensation for powered-lift STOL aircraft*. NASA TM-X-62363, 1974. AIRCRAFT HANDLING.

NINCIC, G. and PAVICIC, D. *Use of flight simulators in aircraft accident analyses*. Proceedings of 1st Yugoslav Aerocosmonautics Conference, Belgrade, Yugoslavia, May 1973. (In Serbo-Croat). GENERAL and THEORETICAL.

NYLEN, W.E. *Engineering simulation development and evaluation of the two-segment noise abatement approach conducted in a B 727-222 flight simulator*. NASA CR-137594, 1974. AIRCRAFT HANDLING.

OLDFIELD, D.E. and HORNER, R.M. *A simulator assessment of three height presentations on a HUD*. RAE TM-Avionics-122, 1972. CONTROLS and DISPLAYS.

ONKEN, R., ADAM, V. and DIERKE, R. *The use of a flight simulator in the synthesis and evaluation of new command control concepts*. Proceedings of AGARD FMP/GCP Symposium 'Flight Simulation/Guidance Systems Simulation', The Hague, Netherlands, October 1975. CONTROLS and DISPLAYS.

ONTIVEROS, R.J. *Capabilities necessary, characteristics and effectiveness of pilot ground trainers. Phase II. Visual reference flight manoeuvres*. FAA NA-73-15, 1973. TRAINING.

ONTIVEROS, R.J. *Effectiveness of a pilot ground trainer as a part-task IFR flight-checking device. Stage 1. Interim Report Apr-Sept 1974*. FAA NA-74-51, 1975. TRAINING.

van OOSTEROM, T. *Measurements on the relation between magnitude and duration, and on the rate of application of the control forces achieved by pilots in simulated manoeuvres*. AGARD R-241, 1959. AIRCRAFT HANDLING.

ORNSTEIN, G.N., NICHOLS, I.A. and FLEXMAN, R.E. *Evaluation of a contact flight simulator when used in an A.F. primary flight training programme: Part II. Effectiveness of training on component skills*. APTRC TR-54-110, 1954. TRAINING.

PALMER, W.E. *A flight simulator study of the lateral-directional stability requirements of piloted air vehicles.* NA 61H-241, 1961. AIRCRAFT HANDLING.

PALMER, E. and PETITT, J. *Visual space perception on a computer graphics night visual attachment.* Proceedings of AIAA Visual and Motion Simulation Conference, Dayton, Ohio, U.S.A., April 1976a. VISUAL CUES.

PALMER, E. and PETITT, J. *Difference thresholds for judgements of sink rate during the flare.* Proceedings of AIAA Visual and Motion Simulation Conference, Dayton, Ohio, U.S.A., April 1976b. VISUAL CUES.

PANGBURN, R.C., METZLER, T.R. and KLINE, J.M. *Pilot performance as a function of three types of altitude displays.* FAA RD-72-130, 1972. CONTROLS and DISPLAYS.

PARRISH, R.V. and MARTIN, D.J. *Evaluation of a linear washout for simulator motion cue presentation during landing approach.* NASA TN-D-8036, 1975. MOTION CUES.

PARRISH, R.V., ROLLINS, J.D. and MARTIN, D.J. *Visual/motion simulation of CTOL flare and touchdown comparing data obtained from two model board display systems.* Proceedings of AIAA Visual and Motion Simulation Conference, Dayton, Ohio, U.S.A., April 1976. (Loose paper). VISUAL CUES.

PAYNE, T.A., DOUGHERTY, D.J., HASLER, S.G., SKEEN, J.R., BROWN, E.L. and WILLIAMS, A.C. *Improving landing performance using a contact landing trainer.* SDC 71-16-11, 1954. VISUAL CUES.

PERRY, D.H. *Flight simulators and the study of aircraft handling characteristics.* RAE TOLS/7, December 1962. AIRCRAFT HANDLING.

PERRY, D.H. *Flight simulation - some aspects of its use for studies of aircraft handling qualities.* RAE TM-Aero-952, 1966. AIRCRAFT HANDLING.

PERRY, D.H. and BURNHAM, J.A. *A flight simulator study of difficulties in piloting large jet transport aircraft through severe atmospheric turbulence.* MOD Aeronautical Research Council, London. Report CP-906, September 1965. AIRCRAFT HANDLING.

PERRY, D.H. and NAISH, J.M. *Flight simulation for research.* Journal of the Royal Aeronautical Society, 1964, 68, 645-660. GENERAL and THEORETICAL.

PETIT, J.P. and RAYNAL, J.C. *Etude au simulator du pilotage d'un avion STOL en approach.* Proceedings of AGARD FMP/GCP Symposium 'Flight Simulation/Guidance Systems Simulation', The Hague, Netherlands, October 1975. (In French). CONTROLS and DISPLAYS.

PFEIFFER, M.G., CLARK, W.C. and DANAHER, J.W. *The pilot's visual task: A study of visual display requirements.* NTDC 783-1, March 1963. VISUAL CUES.

PIRANIAN, A.G. *The effect of the individual and combined stresses of vibration and sustained "g" on pilot performance.* AGARD CP-145, 1975. HUMAN PERFORMANCE.

POMAROLLI, R.S. *The effectiveness of the Naval Air Basic Instrument Trainer (NAVbit).* Naval Aerospace Medical Institute, Pensacola, Florida, U.S.A. Special Report 65-7, 1965. TRAINING.

POULTER, R.F. and WILSON, R.V. *Pilots' assessment of a pitch motion system for a flight simulator.* IAM S-82, 1968. MOTION CUES.

POVENMIRE, H.K. and ROSCOE, S.N. *An evaluation of ground-based trainers in routine primary flight training.* Human Factors, 1971, 13, 109-116. TRAINING.

POVENMIRE, H.K. and ROSCOE, S.N. *Incremental transfer effectiveness of a ground-based general aviation trainer.* Human Factors, 1973, 15, 534-542. TRAINING.

PRILLIMAN, F.W., HUFF, W.W. and HOOKS, J.T. *A manned air-to-air combat simulator.* Journal of Aircraft, 1969, 6, 353-359. VISUAL CUES.

PROPHET, W.W. and BOYD, H.A. *Device-task fidelity and transfer of training: Aircraft cockpit procedures training.* HumRRO TR-70-10, 1970. TRAINING.

PROPHET, W.W., CARO, P.W. and HALL, E.R. *Some current issues in the design of flight training devices.* HumRRO PP-5-72, 1972. TRAINING.

QUEIRO, M.J. and RILEY, D.R. *Fixed-base simulator study of the effect of time delays in visual cues on pilot tracking performance.* NASA TN-D-8001, 1975. CONTROLS and DISPLAYS.

QUIGLEY, H.C. *Simulation techniques for the study of V/STOL problems.* AGARDograph 99, 1964. AIRCRAFT HANDLING.

QUIGLEY, H.C. and HOLZHAUSER, C.A. *Requirement for simulation in V/STOL research aircraft programmes.* Proceedings of Fluid Dynamics Panel Symposium, Delft, Netherlands, April 1974. AIRCRAFT HANDLING.

RAGLAND, S., CHAMBERS, R.M., CROSBIE, R.J. and HITCHCOCK, L. *Simulation and effects of severe turbulence on jet airline pilots.* NADC ML-6411, 1964. MOTION CUES.

RATHERT, G.A., CREER, B.Y. and DOUVILLIER, J.G. *Use of flight simulators for pilot-control problems.* NASA M-3-6-59A, February 1959. MOTION CUES.

RATHERT, G.A., CREER, B.Y. and SADOFF, M. *The use of piloted flight simulators in general research.* AGARD R-365, 1961. MOTION CUES.

RAWSON, H.E. *Flight simulator study of human performance during low-altitude high-speed (LAHS) flight.* ATRECOM TR-63-52, 1963. HUMAN PERFORMANCE.

REEDER, J.P. *What's important in simulation?* 21st Flight Safety Foundation Annual International Air Safety Seminar, Anaheim, California, U.S.A., October 1968. GENERAL and THEORETICAL.

REID, G.B. *Training transfer of a formation flight trainer.* Human Factors, 1975, 17, 470-476. TRAINING.

RENEMANN, H.H. *Crew training in a flight simulator in case of pilot incapacitation.* DGLR Anthropotechnicians Committee, 16th Meeting, Frankfurt, Germany, November 1974. (In German). TRAINING.

REYNOLDS, P.A. *Flight simulation.* Astronautic and Aeronautics, July-Aug 1974, 12, 58-63. GENERAL and THEORETICAL.

REYNOLDS, R.A., WIRTH, F.A. and MATHEWS, R.H. *Cost-effective use of flight simulation.* AIAA 75-329, 1975. GENERAL and THEORETICAL.

RHODES, J. *The urgent need for flight simulators for present and future aircraft.* SAE 670297, 1967. GENERAL and THEORETICAL.

RICH, P.M., CROOK, W.G., SULZER, R.L. and HILL, P.R. *Reaction of pilots to warning systems for visual collision avoidance.* SAE 720312, 1972. CONTROLS and DISPLAYS.

RINGHAM, G.B. *Flight simulation.* Journal of the Royal Aeronautical Society, 1954, 58, 153-172. GENERAL and THEORETICAL.

RINGLAND, R.F., STAPLEFORD, R.L. and MAGDALENO, R.E. *Motion effects on an IFR hovering task: Analytical predictions and experimental results.* NASA CR-1933, 1971. MOTION CUES.

RITCHIE, M.L. and HANES, L.F. *An experimental analysis of transfer effects between contact and instrument flight.* AD-816-553, June 1964. TRAINING.

ROLFE, J.M. *Vehicle simulation for training and research.* IAM R-442, 1968. GENERAL and THEORETICAL.

ROLFE, J.M., CHAPPELOW, J.W., EVANS, R.L., LINDSAY, S.J.E. and BROWNING, A.C. *Evaluating measures of workload using a flight simulator.* AGARD CP-146, 1974. HUMAN PERFORMANCE.

ROLFE, J.M., HAMMERTON-FRASER, A.M., POULTER, R.F. and SMITH, E.M.B. *Pilot response in flight and simulated flight.* Ergonomics, 1970, 13, 761-768. MOTION CUES.

ROOT, R.T. *An annotated bibliography of research on training aids and training devices.* AD 637-219, 1957. GENERAL and THEORETICAL.

ROSCOE, A.H. and GOODMAN, E.A. *An investigation of heart-rate changes during a flight simulator approach and landing task.* RAE TM-Avionics-155, 1973. HUMAN PERFORMANCE.

- ROSCOE, S.N. *Incremental transfer and cost-effectiveness of flight training simulators*. ARL 74-8/AFOSR 74-5, 1974. TRAINING.
- ROSCOE, S.N. *Effective and economical simulation in the design and use of aero-systems*. Interim Report. ARL 75-8/AFOSR 75-3, 1975. GENERAL and THEORETICAL.
- ROSCOE, S.N., DENNEY, D.C. and JOHNSON, S.L. *The frequency-separated display principle: Phase III*. ARL 71-15, 1971. CONTROLS and DISPLAYS.
- ROSCOE, S.N. and KRAUS, E.F. *Pilotage error and residual attention -- the evaluation of a performance control system in airborne area navigation*. Navigation, 1973, 20, 267-279. CONTROLS and DISPLAYS.
- RUBEN, H.D. *Pilot performance monitoring and recording in flight simulators*. Proceedings of R.Ae.S. Symposium 'Flight Training Simulators for the 70s', London, England, October 1970. TRAINING.
- RUNYON, R., GORDON, N.B. and CHAJET, G. *Relative motion training (a preliminary analysis)*. NTDC 20-RM-1-1M, September 1958. TRAINING.
- RUOCCO, J.N., VITALE, P.A. and BENFARI, R.C. *Kinetic cueing in simulated carrier approaches*. NTDC 1432-1, 1965. MOTION CUES.
- SADOFF, M. *The effects of longitudinal control-system dynamics on pilot opinion and response characteristics as determined from flight tests and from ground simulator studies*. NASA M-10-1-58A, 1958. AIRCRAFT HANDLING.
- SADOFF, M. *A study of a pilot's ability to control during simulated stability augmentation systems failures*. NASA TN-D-1552, 1962. AIRCRAFT HANDLING.
- SADOFF, M., McFADDEN, N.M. and HEINLE, D.R. *A study of longitudinal control problems at low and negative damping and stability, with emphasis on effects of motion cues*. NASA TN-D-348, 1961. MOTION CUES.
- SAE COMMITTEE AGE-3, TRAINING EQUIPMENT, PROGRAMS and SIMULATION. *The measurement of trainee performance in simulators and part-task trainers*. SAE 735103 (AIR-1054-A), 1972. TRAINING.
- SAGER, D. *Simulator evaluation of manually-flown curved Microwave Landing System approaches*. Proceedings of IEEE International Conference 'Systems, Man and Cybernetics', Dallas, Texas, U.S.A., October 1974. CONTROLS and DISPLAYS.
- SCHAUMBERG, G.F. and HEAPY, R.J. *Evaluation of an airseat as a limited cockpit motion system*. McDonnell-Douglas Corporation, Douglas Aircraft Company, 3855 Lakewood Blvd, Long Beach, California 90801, U.S.A. MDC J-0071, 1969. MOTION CUES.
- SCHMIDT, S.F. and CONRAD, B. *Motion drive signals for piloted flight simulators*. NASA CR-1601, 1970. MOTION CUES.
- SCHOHAN, B. *Human factors recommendations for the design of cockpit procedures trainers*. WADC TR-56-527, September 1958. GENERAL and THEORETICAL.
- SCHOHAN, B., RAWSON, H.E. and SOLIDAY, S.M. *Pilot and observer performance in simulated Low-Altitude High-Speed (LAHS) flight*. Human Factors, 1965, 7, 257-265. HUMAN PERFORMANCE.
- SCHULZ, U. and SEELMANN, H. *Views regarding the validity of results from simulation testing in comparison with the results from actual flight test*. NASA TT-F-15172, 1973. GENERAL and THEORETICAL.
- SCHWEINFURTH, R. *Applicability of flight simulators with no visual or motion cues*. DGLR 70-070, 1970. (In German). VISUAL CUES.
- SECKEL, E., HALL, I.A.M., McRUER, D.T. and WEIR, D.H. *Human pilot dynamic response in flight and simulator*. WADC TR-57-520, 1958. HUMAN PERFORMANCE.
- SHIPLEY, B.D., GERLAKE, V.S. and BRECKE, F.H. *Measurement of flight performance in a flight simulator*. Interim Report. AFOSR-75-0208TR, 1975. HUMAN PERFORMANCE.

SHIRLEY, R.S. and YOUNG, L.R. *Motion cues in man-vehicle control*. IEEE Transactions on Man-Machine Systems, Dec 1968, MMS-9, 121-128. MOTION CUES.

SILVERTHORN, J.T. and SWAIM, R.L. *Manual control displays for a four-dimensional landing approach*. NASA TM-X-62464, 1975. CONTROLS and DISPLAYS.

SINACORI, J.B. *Validation of ground-based simulation*. AHS Preprint, 362, 1969. GENERAL and THEORETICAL.

SISSEL, M. and SMITH, W.D. *A preliminary training study of the H-34 cockpit procedures trainer*. U.S. Army Aviation Human Research Unit, Fort Rucker, Alabama, U.S.A. Research Memo N.6, October 1960. TRAINING.

SKANS, S. *The specification of requirements for flight simulation*. Proceedings of R.Ae.S. Symposium 'Theory and Practice in Flight Simulation', London, England, April 1976. MOTION CUES.

SMITH, A.H., BACON, E.A.H., COOK, T.W. and MAEERS, S.P. *The problem of the utility of the flight simulator*. Defence Research Establishment, Toronto, Canada. DRML 154-33-67-1, 1954. GENERAL and THEORETICAL.

SMITH, R.P., LYTWYN, R.T. and WHITE, F. *Analysis, simulation and piloted performance of advanced tandem-rotor helicopters in hover*. AHS Preprint 843, 1974. AIRCRAFT HANDLING.

SMITH, R.L., PENCE, G.G., QUEEN, J.E. and WULFECK, J.W. *Effect of a predictor instrument on learning to land a simulated jet trainer*. AFOSR 74-1731TR, 1974. CONTROLS and DISPLAYS.

SMODE, A.F. *Recent developments in instructor station design and utilisation for flight simulators*. Human Factors, 1974, 16, 1-18. GENERAL and THEORETICAL.

SNYDER, C.T., BRAY, R.S., DRINKWATER, F.J. and FORREST, R.D. *Simulation studies for development of certification criteria applicable to SST take-off*. NASA SP-270, 1971. AIRCRAFT HANDLING.

SNYDER, C.T. and JACKSON, C.T. *A piloted simulator study of take-off performance and handling qualities of a double-delta supersonic transport*. NASA TN-D-4396, 1968. AIRCRAFT HANDLING.

SOLIDAY, S.M. *Navigation in terrain-following flight*. Human Factors, 1970, 12, 425-433. CONTROLS and DISPLAYS.

SOLIDAY, S.M. and MILLIGAN, J.R. *Terrain-following with a head-up display*. Human Factors, 1968, 10, 117-126. CONTROLS and DISPLAYS.

SOLIDAY, S.M. and SCHOHAN, B. *A simulator investigation of pilot performance during extended periods of Low-Altitude High-Speed (LAHS) flight*. NASA CR-63, 1964. HUMAN PERFORMANCE.

SOLIDAY, S.M. and SCHOHAN, B. *Task-loading of pilots in simulated Low-altitude high speed flight*. Human Factors, 1965, 7, 45-53. HUMAN PERFORMANCE.

SPANGLER, R.M. and SULZER, R.L. *Flight simulation study of air-to-air ranging displays for separation assurance*. FAA NA-68-13 (RD-66-83), 1966. CONTROLS and DISPLAYS.

SPOONER, A.M. *The development of visual systems for flight simulation*. Proceedings of Second R.Ae.S. Flight Simulation Symposium, London, England, May 1973. VISUAL CUES.

STANEK, P. *Study of capabilities, necessary characteristics and effectiveness of pilot ground trainers*. Vol. I. FAA RD-72-127, I, 1973. TRAINING.

STAPLEFORD, R.L., HEFFLEY, R.K., JEWELL, W.F., LEHMAN, J.M., HYNES, C.S. and SCOTT, B.C. *A STOL airworthiness investigation using a simulation of a deflected slipstream transport*. Vol. 2: *Simulation data and analysis*. NASA TM-X-62393, 1974. AIRCRAFT HANDLING.

STAPLEFORD, R.L., HEFFLEY, R.K., RUMOLD, R.C., HYNES, C.S. and SCOTT, B.C. *A STOL airworthiness investigation using a simulation of a deflected slipstream transport*. Vol. 1: *Summary of results and airworthiness implications*. NASA TM-X-62392, 1974. AIRCRAFT HANDLING.

STAPLES, K.J. *Motion, visual and aural cues in piloted flight simulation*. AGARD CP-79-70, 1970. MOTION CUES.

STARK, E.A. *Motion perception and terrain visual cues in air combat simulation*. Proceedings of AIAA Visual and Motion Simulation Conference, Dayton, Ohio, U.S.A., April 1976. MOTION CUES.

STARK, E.A. and WILSON, J.M. *Visual and motion simulation in flying manoeuvring*. AIAA 73-934, 1973. MOTION CUES.

STAVE, A.M. *Effects of helicopter noise and vibration on pilot performance (as measured in a fixed-base flight simulator)*. NASA CR-132347, 1973. HUMAN PERFORMANCE.

STEWART, J.D. *Human perception of angular acceleration and implications in motion simulation*. AIAA 70-350, March 1970. MOTION CUES.

STINNETT, G.W. *Pilot simulator studies of new aircraft missions*. AGARDograph 99, 1964. AIRCRAFT HANDLING.

STONE, R.W. *Ride quality - an exploratory study and criteria development*. NASA TM-X-71922, 1974. MOTION CUES.

STONE, R.W. *Simulator studies and psychophysical ride-comfort models*. NASA TM-X-3295, 1975. MOTION CUES.

SULZER, R.L. *A system of low-cost visual collision avoidance training*. National Aviation Facilities Experimental Centre, FAA, Atlantic City, New Jersey, U.S.A. 1971. TRAINING.

SULZER, R.L. and CROOK, W.G. *Evaluation of low-cost collision avoidance ground training equipment*. FAA NA-68-37, 1968. VISUAL CUES.

SWANSON, A.M. *Notes on simulator instrumentation for measurement of pilot proficiency*. AFPTRC TM: OL-TM-57-3, 1957. HUMAN PERFORMANCE.

TAIT, D.R. *The Next generation of visual systems*. Proceedings of R.Ae.S. Symposium 'Flight Training Simulators for the 70s', London, England, October 1970. VISUAL CUES.

TARDY, J. *Methods used for optimising the simulation of the Concorde SST using flight test results*. AGARD CR-172, 1975. GENERAL and THEORETICAL.

TAYLOR, L.W. and DAY, R.E. *Flight controllability limits and related human transfer functions as determined from simulator and flight tests*. NASA TN-D-746, 1961. AIRCRAFT HANDLING.

TERRY, R.P. *Selecting a basic flight procedure trainer*. Shell Aviation News, 1972, No. 406, 8-11. TRAINING.

TERRY, R.P. *Towards jet indoctrination*. Shell Aviation News, 1973, No. 416, 20-23. TRAINING.

THOMAS, W.L. *The use of Specific Behavioural Objectives (SBO) in simulator and curriculum development and other simulator uses*. Proceedings of Second R.Ae.S. Flight Simulation Symposium, London, England, May 1973. TRAINING.

TOMLINSON, B.N. *The simulation of turbulence and its influence on the pilot*. RAE TM: Aero 1314, 1971. AIRCRAFT HANDLING.

TREMBLAY, H.G., BROWN, J.L. and FUTTERWEIT, A. *Application of harmonic analysis in a study of tracking performance in a TV-2 aircraft and in centrifuge and stationary simulations of that aircraft*. NADC AC-6406, April 1964. MOTION CUES.

VALVERDE, H.H. *Flight simulators. A review of the research and development*. AMRL TR-68-67, 1968. GENERAL and THEORETICAL.

VALVERDE, H.H. *A review of flight simulator transfer of training studies*. Human Factors, 1973, 15, 510-523. TRAINING.

VANDERKOLK, R.J. and ROSCOE, S.N. *Simulator tests of pilotage error in area navigation with vertical guidance - effects of descent angle and display scale*. Human Factors Society, 17th Annual Meeting, Washington DC, U.S.A., October 1973. CONTROLS and DISPLAYS.

VINCENT, J.H. *STOL tactical aircraft investigation, Volume 5 Part 2: Flight control technology: Piloted simulation of a medium STOL transport with vectored thrust mechanical flaps*. Final Technical Report, June 1971-Dec 1972. AFFDL TR-73-19, 1973. AIRCRAFT HANDLING.

VINJE, E.W. *An analysis of pilot adaptation in a simulator multiloop VTOL hovering task.* IEEE Transactions on Man-Machine Systems, December 1968, MMS-9, 110-120. HUMAN PERFORMANCE.

VINJE, E.W. *Flight simulator evaluation of control-moment usage and requirements for V/STOL aircraft.* AHS Preprint 743, 1973. AIRCRAFT HANDLING.

VOGL, E. *Visual simulation for visual flight conditions.* Deutsche Gesellschaft für Ortung und Navigation, Nationale Tagung über Simulation im Dienste des Verkehrs, Bremen, W. Germany. Paper 3.5, April 1975. (In German). VISUAL CUES.

VOMASKE, R.F., SADOFF, M. and DRINKWATER, F.J. *The effect of lateral-directional control coupling on pilot control of an airplane as determined in flight and in a fixed-base simulator.* NASA TN-D-1141, 1961. AIRCRAFT HANDLING.

VREULS, D., OBERMAYER, R.W. and GOLDSTEIN, I. *Trainee performance measurement development using multivariate measure selection techniques.* Final Report. Dec 1972 Dec 1973. NAVTRAEQUIPCEN-73-C-0066-1, 1974. TRAINING.

WATANABE, A. and HORIKAWA, Y. *Simulation study on flare control system by optimisation theory.* National Aerospace Laboratory, Tokyo, Japan. NAL TR-312, 1973. (In Japanese). AIRCRAFT HANDLING.

WATERS, B.K., GRUNZKE, P.M., IRISH, P.A. and FULLER, J.H. *Preliminary investigation of motion, visual and g-seat effects in the Advanced Simulator for Undergraduate Pilot Training (ASUPT).* Proceedings of AIAA Visual and Motion Simulation Conference, Dayton, Ohio, U.S.A., (Loose Paper). April 1976. MOTION CUES.

WAUGH, J.P. *Pilot performance in a helicopter simulator.* Final Technical Memorandum. Human Engineering Laboratories, Aberdeen Proving Ground, Maryland, U.S.A. HEL TM-23-75, 1975. CONTROLS and DISPLAYS.

WEENER, E.F. *The effect of simulator dynamics on pilot response.* NASA CR-132459, 1974. CONTROLS and DISPLAYS.

WEIR, D.H. and JOHNSON, W.A. *Pilot dynamic response to sudden flight control system failures and implications for design.* NASA CR-1087, 1968. HUMAN PERFORMANCE.

WEIR, D.H. and KLEIN, R.H. *The measurement and analysis of pilot scanning and control behaviour during simulated instrument approaches.* NASA CR-1535, 1970. CONTROLS and DISPLAYS.

WEIR, D.H. and McRUER, D.T. *Pilot dynamics for instrument approach tasks: Full panel multi-loop and flight director operations.* NASA CR-2019, 1972. HUMAN PERFORMANCE.

WEMPE, T.E. *Fixed-base simulator evaluation of a pilot's terrain-following display with various modes of presenting information.* NASA TN-D-1827, 1964. CONTROLS and DISPLAYS.

WEMPE, T.E. *Effects of gust-induced and manoeuvring acceleration stress on pilot-vehicle performance.* Aerospace Medicine, 1965, 36(3), 246-255. MOTION CUES.

WEWERINKE, P.H. and SMIT, J. *A simulator study to investigate human operator workload.* AGARD CP-146, 1974. HUMAN PERFORMANCE.

WHITE, M.D. and COOPER, G.E. *A piloted simulation study of operational aspects of the stall pitch-up.* NASA TN-D-4071, 1967. AIRCRAFT HANDLING.

WHITTINGTON, A.C. *An exploratory experiment to validate the use of heart-rate as a measure for inter-task stress in a piloted flight simulator.* RAE TM-Aero-1236, 1970. HUMAN PERFORMANCE.

WICK, R.L., BILLINGS, C.E., GERKE, R.J. and CHASE, R.C. *Aircraft-simulator transfer problems.* AMRL TR-74-68, 1974. HUMAN PERFORMANCE.

WILCOCK, T. and THORPE, A.C. *Flight simulation of a Wessex helicopter: A validation exercise.* RAE TR-73096, 1973. AIRCRAFT HANDLING.

WILCOCK, T. and TOMLINSON, B.N. *Flight simulation in helicopter and V/STOL research.* Proceedings of Second R.Ae.S. Flight Simulation Symposium, London, England, May 1973. AIRCRAFT HANDLING.

WILCOXON, H.C. and DAVY, E. *Fidelity of simulation in Operational Flight Trainers (OFTs). Part I. Effectiveness of rough air simulation.* SDC 999-2-3a, 1954a. MOTION CUES.

WILCOXON, H.C. and DAVY, E. *Fidelity of simulation in Operational Flight Trainers. Part II. The effect of variation in control loadings on the training value of the SNJ OFT.* SDC 999-2-3b, 1954b. CONTROLS and DISPLAYS.

WILCOXON, H.C., DAVY, E. and WEBSTER, J.C. *Evaluation of the SNJ Operational Flight Trainer (OFT).* SDC 999-2-1, 1954. TRAINING.

WILCOXON, H.C. and WEBSTER, J.C. *Survey utilisation of fleet-type Operational Flight Trainers (OFTs).* SDC 999-2-2, 1954. GENERAL and THEORETICAL.

WILKERSON, L.E. and MATHENY, W.G. *Discrimination and control of pitch, roll and yaw with a grid to encode the ground plane.* BHC D-228-421-003, 1960. VISUAL CUES.

WILLIAMS, A.C. and FLEXMAN, R.E. *An evaluation of the Link SNJ operational trainer as an aid in contact flight training.* SDC 71-16-5, 1949. TRAINING.

WILLIAMS, A.C. and ROSCOE, S.N. *Pilot performance in instrument flight as a function of the extent and distribution of the visible horizon.* SDC 71-16-3, 1949. CONTROLS and DISPLAYS.

WILLIGES, B.H., ROSCOE, S.N. and WILLIGES, R.C. *Synthetic flight training revisited.* Human Factors, 1973, 15, 543-560. TRAINING.

WILLIGES, R.C., HOPKINS, C.O. and ROSE, D.J. *Effects of aircraft simulator motion cue fidelity on pilot performance.* Deutsche Gesellschaft für Ortung und Navigation, Nationale Tagung über Simulation im Dienste des Verkehrs, Bremen, W. Germany. Paper 1.2, April 1975. (In German). MOTION CUES.

WILLIGES, R.C. and ROSCOE, S.N. *Simulator motion in aviation system design research.* ARL 73-6/ONR 73-2/AFOSR 73-3, 1973. MOTION CUES.

WILSON, D. *Visual simulation -- where we are -- where we are going.* SAE 670303, 1967. VISUAL CUES.

WILSON, D. *Advances in motion platform systems.* Proceedings of R.Ae.S. Symposium 'Flight Training Simulators for the 70s', London, England, October 1970. MOTION CUES.

WILSON, J.M., ZEFFERT, H. and WILKEY, A.D. *The need for mock-ups and simulators.* Proceedings of R.Ae.S. Symposium 'Flight Deck Environment and Pilot Workload', London, England, March 1973. HUMAN PERFORMANCE.

WILSON, W.B. *The effect of prolonged non-flying periods on pilot skill in performance of a simulated carrier landing task.* AD 769696, 1973. TRAINING.

WIRTH, F.A. *Flight simulator development in parallel with aircraft flight test.* SAE 720858, 1972. GENERAL and THEORETICAL.

WOLF, J.D. *An experimental evaluation of aircraft displays for IFR steep-angle approaches.* Proceedings of IEEE-GMMS ERS International Symposium 'Man-Machine Systems', Cambridge, England, September 1969. CONTROLS and DISPLAYS.

WOODEN, W.A. and COWELL, J.D. *Optimising the use of the flight simulator.* Proceedings of Second R.Ae.S. Flight Simulation Symposium. London, England, May 1973. GENERAL and THEORETICAL.

WOODRUFF, R.R. and SMITH, J.F. *T-4G simulator and T-4 ground training devices in USAF Undergraduate Pilot Training (UPT).* Final Report Feb 1972-June 1973. AFHRL TR-74-78, 1974. TRAINING.

WOODRUFF, R.R., SMITH, J.F. and MORRIS, R.A. *Use of the T-4G simulator in USAF Undergraduate Pilot Training (UPT). Phase I.* Final Report. AFHRL TR-74-61, 1974. TRAINING.

WRENNINGE, B. *A simulator investigation to find suitable command signals for a three degree-of-freedom simulator motion system.* Department of Aeronautics, Royal Institute of Technology, Stockholm, Sweden. 1967. MOTION CUES.

WULFECK, J.W., PROSIN, D.J. and BURGER, W.J. *Effect of a predictor display on carrier landing performance. Part I: Experimental evaluation.* Final Report. AD-767982, 1973. CONTROLS and DISPLAYS.

YOUNG, L.L., JENSEN, R.S. and TRAICHE, C.W. *Use of a visual landing system in primary flight training.* ARL 73-26/AFOSR 73-17, 1973. CONTROLS and DISPLAYS.

ZAITZEFF, L.P. *Aircrew task loading in the Boeing multimission simulator.* AGARD CP-56, 1969. HUMAN PERFORMANCE.

ZUCCARO, J.J. *The Flight Simulator for Advanced Aircraft (FSAA) — a new aeronautical research tool.* AIAA 70-359, 1970. MOTION CUES.

**SUBJECT INDEX**

## GENERAL AND THEORETICAL

ALLISON, W.A. *Naval Air Test Centre participation in development of air-to-air combat simulation*. AIAA 72-765, 1972.

The kind of flight test activity which would assist in the development of air-to-air combat simulators is discussed. Topics covered include aircraft data requirements, simulation of the cockpit area, visual presentations, and pilot cues of aircraft behaviour.

ALLRED, G.A. *Future trends in aircraft simulation*. British Airline Pilots' Association Technical Symposium, Middlesex, England, November 1968.

A goal of simulation for airlines is to get all training/checking into the flight simulator. Safety, quality of training and checking and economic factors motivate the user toward this goal. New developments in motion and visual systems promise great improvement in the art of simulation. Attainment of realistic cues, both visual and kinaesthetic, is an essential ingredient in a simulator programme for adequate and successful training. Use of the vast potential of modern digital simulator computers to assist the training/checking function through programmed routines, automatic evaluation against an established standard and record of performance is a forecast reality. These features are now often specified in the new family of advanced simulators on order for such aircraft as the B-747. Accident investigation assistance is being provided by the installation of equipment for simulator replay of aircraft-generated, computer-stored flight parameter information. The past trend towards reduction of aircraft training time through use of the simulator has a corollary in the trend towards the reduction of increasingly expensive simulator time by use of a cockpit procedures trainer—a cockpit-oriented training tool with aircraft systems but without flight logic. Similarly, VST/TIFS in-flight simulation techniques are being advanced by some companies as a means of diverting training from revenue-earning line aircraft. Pilot understanding and acceptance of improved, yet economic, training and checking goals is vital to the team effort needed to enhance safety through training.

BELLM, R.H.J. *An appraisal of current shortcomings in the procurement and commissioning processing of flight simulators*. Proceedings of R.Ae.S. Symposium 'Flight Training Simulators for the 70s', London, England, October 1970.

The speaker complained of the protracted proceedings involved in the procurement and commission of simulators for airline use. There are six stages in procurement viz:

1. Preparation of the requirement.
2. Invitations to manufacturers to tender.
3. Preparation of proposals by manufacturers.
4. Evaluation of these proposals by the airlines.
5. Survey of products and company performance, and
6. Negotiation of the specification.

Because of the length of time involved in preliminaries, a large proportion of simulators were delivered late so, in part, decreasing their value during the introduction of a new aircraft. The situation was not helped by each customer's whims and the large number of variations in the hardware which could be specified. The airlines must streamline these variations, so helping not only the manufacturers but themselves. Areas where agreement could be achieved included:

- (a) Standards for simulated instruments.
- (b) Standards for the instructor's panel.
- (c) Equipment environmental needs.
- (d) Availability of space channels and wiring, and
- (e) Definition of reliability.

After the basic paperwork, there came the problem of data and aircraft parts acquisition. The aircraft manufacturers came in for criticism in their apparent lack of interest in providing this data. The aircraft firms would only appreciate the problems when they themselves needed simulators for a training task as opposed to research. The acceptance programmes were a further area where agreement among airlines was needed, in particular in the documentation. The acceptance checks were often protracted because of the repeated process of offer and rejection. Often airlines were offered simulators for acceptance with less than half the agreed checks being satisfied. A further area where improvement was vital was that of maintenance engineer training on the equipment. Once again the simulator makers were in a difficult situation in that they did not normally have a suitable simulator available for any length of time. This should be remedied.

BRISSENDEN, R.F. *Using simulation for research and using research to develop valid simulation techniques*. SAE 670309, 1967.

The author outlines the main factors involved in designing simulators that have desirable fidelity without being overdesigned. A closed-loop logic for the development and use of simulation is set forth. The simulation approach is developed round three basic design categories, (1) computer and servo-mechanism technology, (2) human engineering criteria, and particularly a better understanding of instrumentation system requirements to provide adequate realism, and (3) control information. In a discussion on display systems, the author points out the great

amount of equipment that is available for the simulator designer's use. Some fixed and moving-base research simulators in use at Langley Research Centre are presented to illustrate specific applications of various display designs and to show regions where motion cues may be used to advantage.

BRUNING, G. *Simulation, an introduction and survey*. AGARD CP-79-70, 1971.

The author opens with a review of the achievements in simulation to date. After a short discussion about the different definitions of the term "simulator", he explains the analytical treatment of simulation along general lines. Use is made in this connection of the linearised control theory. Some typical examples of fixed-base, kinetic and in-flight simulators and their uses are elaborated on, particularly their application to V/STOL problems. A review is given of motion, visual and psychological cues, methods for their simulation and their influence on the quality of simulation. The evaluation of results can only partly be done by quantitative measurements. Of equal importance are pilot opinion ratings. The author deals with differences between simulation on the ground and in the air and he deplores the use of simulation merely as a data production facility. Each type of simulator has a specific region of reasonable use and it is essential for the experimenter to match the simulator used to the task in hand.

BURROWS, A.A. *Human factors in flight training*. Flight Safety Foundation 21st Annual International Air Safety Seminar, Anaheim, California, U.S.A., October 1968.

The author discusses the importance of human factors techniques in non-military flight training. It is stressed that human factors techniques have not always received appropriate application in non-military flight training though there are current trends to remedy this. In particular, the flight simulator and its systematic use provide a key to the immediate future.

CHAPPELOW, J.W. and LAKIN, T. *Pilot opinion on simulation*. Proceedings of R.Ae.S. Second Flight Symposium, London, England, May 1973.

This report describes two pilot opinion surveys regarding simulation. One study was conducted by BALPA and involved 400 airline pilots and the other, undertaken by the IAM, implicated 500 RAF instructors and aircrew.

#### *Findings*

The authors conclude that the most important motion simulations are in pitch, roll, yaw, turbulence and vibration. All the simulators visited had, at least, pitch and roll motion systems. The simulation of these motions was categorised as "quite realistic". As regards the "outside world" view, a visual system is most needed during TO, approach and landing, and in low-level missions. Most needs are satisfied by a device presenting only an approach and runway view. Functions which evoked considerable criticism were poor simulation of the aircraft's handling characteristics, poor representation of control lever loadings and "feel". Considering the flight deck environment, cockpit lighting was considered to be adequately represented. Background R/T was a desirable facility, though not generally available. Engine noise was adequately represented but aerodynamic noise was either poorly represented or absent. Regarding transfer, more than 70% of respondents thought that the simulator's success as a training device was satisfactory while 58% thought that the simulator checks for predicting performance in the aircraft were very good or adequate. 90% of the aircrew thought that the instructor needed flying practice on the aircraft being simulated and 89% thought that he needed teacher training. More free time should be available for students to practice weak points. There was general approval for the way the simulator was being used for management, procedural and emergency practice, refresher training, competency checks and IR renewals. Digital programmed simulators (e.g. B 707, BAC 111 and VC 10) were less popular than the analogue-controlled type (e.g. Comet, Trident, Vanguard, Viscount and Britannia). This may be due to the greater degree of serviceability of the latter.

COHEN, E. *Simulators - a training viewpoint*. Flight Simulation Operations, Singer-Link Corporation, Binghamton, New York, U.S.A. Technical Newsletter No. 1, 1972.

The author treats the subject under the headings:-

1. Why simulators and kindred training devices are procured.
2. Why simulators are such effective training tools.
3. Why simulators are not used more, and
4. Factors determining simulator effectiveness.

He gives an annotated list of automated training facilities available on magnetic and computer tape.

#### *Conclusions*

Simulator training can replace most training flight time. While the data supporting this is clear, there is still a lot of opposition to simulator use. Within the constraints of the market place, such resistance will best be overcome by stressing the non-simulation training features of the simulator - not only the extent and fidelity of its simulation - and by paying no less attention to improving instructional features (e.g. feedback to the trainee) than to improving simulation itself (e.g. visual system development).

COLLIN, M.A.B. *The simulator industry and its contribution to military training requirements*. Proceedings of R.Ae.S. Second Flight Simulation Symposium, London, England, May 1973.

The paper contains:

- a. A review of simulator training policy applied over the last five years, with emphasis on the use of the full-

mission simulator in which pains have been taken to recreate, in detail and fidelity, the environment in which the aircrew have to operate. Some of the problems and limitations associated with the operation of full-mission simulators are described.

b. A review of the revised simulator policy, the justification for its implementation and the work in hand to seek scientific evidence to support or refute the latest decisions.

c. An analysis of the contribution that could be made by the simulator industry to RAF simulator training requirements.

COLMAN, K.W., DAVIS, C.G. and COURTNEY, D. *The Operational Flight Trainer in aviation safety*. NTDC 520-1, July 1962.

The authors discuss the contribution Operational Flight Trainers (OFTs) can make towards the reduction of aircraft accidents. They talked to experienced pilots and analysed accident-producing situations. They recommend certain specific action in instructor selection, syllabus construction, instructional techniques and training, and in the design and use of OFTs.

CONANT, J. *Universal Aircraft Flight Simulator/Trainer system definition*. Final technical report. Oct 1969–Sept 1970. ASD TR-70-28, 1970.

In this study, the configuration and performance requirements for the Universal Aircraft Flight Simulator/Trainer (UAFS/T) are defined. Through a review of pertinent literature and from flight test data, an investigation was made of the demands on the human vestibular and visual systems in flight manoeuvres, and quantitative values were found for a desirable cockpit motion system, a visual display system, and for simulated instrument performance characteristics. Appropriate aircraft dynamics were reproduced using mathematical modelling methods, digital computation systems, cockpit motion concepts, and visual image generation and display techniques to determine performance specifications for the UAFS/T.

DAVIES, D.P. *Approval of flight simulator flying qualities*. Aeronautical Journal, 1975, 79, 281-297.

This paper deals with simulators for civil fixed-wing transport aircraft above 20,000 kg maximum weight. Approval procedures in the UK are summarised, the present level of simulator flying qualities is evaluated, and some advice on simulation in general is provided. It is concluded that simulators are not nearly up to the standards claimed and that, even if they do improve in the future, training should include a solid period of flight practice.

DAVIS, J. and BEADSMOORE, E.J. *A military view of flight simulation*. Proceedings of R.Ae.S. Symposium 'Flight Training Simulators for the 70s', London, England, October 1970.

In Part 1 of this treatise, Mr Davis defines the full mission concept and he explains the hardware, taking the Phantom F-4M simulator as typical of R.A.F. requirements, with specific reference to those components which are special to the military role. These include (1) identical cockpits, both front and rear, to those in the aircraft (2) a full emergencies capability (3) three or four degrees of freedom (4) a "g" system (5) a visual system displaying airfield, terrain and weapon attack models (6) a weapons assessment system (7) fully integrated INAS and radar simulation (8) integration of the INAS, radar and weapons assessment systems with each other and with the visual system and (9) digital and hybrid computation. The author discusses the military advantages that accrue from this advanced concept and he mentions the planned uses and savings. In Part 2, Mr Beadsmoore defines the R.N. viewpoint, and ground common to both Services. He shows where the hardware differs to meet the unique R.N. requirements, taking the F-4K Phantom simulator as representative of Navy needs. He mentions how simulators are used in Navy flying training and he describes the Sea King helicopter simulator. In Part 3, both authors consider areas where improvements can lead to enhanced realism in simulation, with consequent benefit to training.

EDENBOROUGH, R.A. *User opinion of RAF flight simulators*. IAM R-433, 1968.

*Object*

To find the opinion of instructors and student pilots about simulators at a number of RAF stations where simulators are used.

*Method*

112 instructors and 128 student pilots completed "open-ended" questionnaire forms. The respondents listed their own comments rather than checking a given list. Using Chi square tests, the responses were analysed under four categories viz:

1. Transports without motion simulation,
2. Bombers without motion simulation,
3. Fighters without motion simulation and
4. Fighters and transports with motion simulation.

The answers of the instructors did not differ significantly from those of the student pilots. Therefore in the statistical analysis no distinction was made.

### Conclusions

1. There was no significant agreement between the four groups about whether motion was an added advantage.
2. As to "g" effects, group 4 subjects showed no significant preference when given the choice between buffeting and 3-axis rotation.
3. Given the option of seven major phases of flight, none of the four groups thought that a visual system was significantly more important in any one particular than in any other.
4. Regarding acceptability, there were significant differences (a) between the four simulator groups, (b) between groups 1 and 2, (c) between groups 1 and 4. Groups 2 and 4 did not differ significantly.

### Recommendations

1. Motion should be provided for pitch, roll, yaw, turbulence, vibration and acceleration effects.
2. Visual aids should be provided for take-off and abort, approach and landing, circuitry, overshoots, transferring from IMC to VMC and vice versa.

EDWARDS, F.L.M. *Designing to satisfy the increased demands in flight simulation*. Civil Aviation Safety Centre Fifth Annual Technical Conference, Beirut, Lebanon, September-October 1970.

This is a review of the history of simulation and a discussion of the current requirements and design problems which arise from these requirements. The use of analogue computers has added to the realism of the aerodynamic side of simulation. The employment of motion platforms with 3 or 6 degrees of freedom is discussed and a colour TV visual system described. Some advanced instructor's facilities and recording, playback and demonstration aids are reviewed.

FAUSET, I.D. *The quantitative evaluation of aircraft flight simulators*. Aviation Psychological Research Centre, Western European Association for Aviation Psychology, Brussels, Belgium. 1973.

The progress made to date is reviewed and the programme for future research into the value of flight simulators in the RAF is outlined. Two main factors have combined to necessitate a more objective approach in assessing the value of simulators. The first is that as front line aircraft have become more complicated the costs per flying hour have risen alarmingly and at the same time aircrew are needing more flying time to achieve operational efficiency. The second factor is that simulator technology has made considerable advances in recent years. Subjective and objective assessment are considered and future proposals are examined.

FERRARESE, J.A. *Assessment of new training systems as substitutes for airborne trainings*. SAE 710476, 1971.

The author reviews progress in the development of simulators as a substitute for airborne training and the evolution of the FA Rules, which have authorised expanded use of these devices. He discusses limitations of current simulators, areas where further development is needed and what he feels the future of simulators will be.

FERROL, M. *Defining synthetics*. Shell Aviation News, 1975, 427, 11-14.

This article is primarily addressed to potential purchasers of flight simulators. It sets out to guide the purchaser into the correct choice by requiring him to answer a series of questions concerning the use to which the simulator will be put, and the training schedule into which it will be introduced. Hopefully the purchaser will buy a tool to do a defined job, rather than an expensive piece of gadgetry.

FLEXMAN, R.E. *Man in the middle. A primer in simulation*. The Connecting Link, 1965, 2(1). Singer-Link Corporation, Binghamton, New York, U.S.A.

The author defines a simulator and sets out its characteristics. He discusses its fidelity, role and use as a training device.

GAGNE, R.M. *Training devices and simulators: Some research issues*. American Psychologist, 1954, 9, 95-107.

The author begins with a definition of training devices and simulators. He describes some research issues occurring in connection with their development, use, and evaluation for training purposes. The main uses of training devices are for performance measurement and performance improvement. When the device is used for performance measurement it is essential that the results are reliable and valid. When it is used for improving performance the important characteristic is the amount of transfer of training achieved. In either case the degree of simulation is of secondary importance. Research opportunities on methodology include job analysis, training, proficiency measurements, and criterion development. Research opportunities on theory include structure of skills, the determinants of human variability, relationships of set and motivation to learning, and mechanisms of transfer of learning. Thus, a training device must either impart training or provide a measure of something. It cannot be justified merely on the basis of looks or similarity to an operational situation.

GERLACH, O.H., BRAY, R.S., COVELLI, D., CZINCZENHEIM, J., HAAS, R.L., LEAN, D., SCHMIDTLEIN, H. and WASICKO, R.J. *Approach and landing simulation*. AGARD R-632, 1975.

The authors were members of a Working Group sponsored by the AGARD Flight Mechanics Panel to examine the

approach and landing stages of simulation. Primarily, non-hardware aspects are considered. Mathematical models are synthesised. The report is in six sections, and an excellent bibliography is appended.

*Introduction.* Historical notes on simulation, progressing from rudimentary displays to current sophisticated simulators, are presented.

*Elements of approach and landing.* For this phase, aircraft models are simplified by the absence of significant aerodynamic effects due to varying Mach number, and only in the case of very large, very flexible planes are aero-elastic effects considered. For STOL and VTOL models, allowances are made for the widely varying interactions between aerodynamics and propulsion.

*External disturbances.* Three categories of external disturbances are considered (1) disturbances due to wind shear and atmospheric turbulence (2) noise in the ILS guidance system and (3) disturbances due to irregularities in the runway surface. The authors illustrate the application of the von Karman, the Dryden and the R.A.E. power spectrum models to low-altitude turbulence, and they question the applicability of cross-power spectra forms.

*Aircraft characteristics.* The kind of data and the degree of detail necessary for the simulation of large subsonic jet transports and powered-lift STOL transports are set out. It is shown how mathematical models differ, depending on the significant aero-dynamic, structural and propulsion characteristics of the aircraft under consideration.

*Visual and motion cues.* Limitations in both day and night landing scenes used in simulations are discussed. Current visual systems are restricted in their field of view, resolution, depth of focus, display, terrain model and dynamic performance. The authors also examine motion cue constraints for both rotational and linear motion. They discuss the use of washout circuitry.

*Simulation development, validation and pilot learning.* Pilots should first gain confidence by simulating aircraft with which they are familiar before carrying out experimental simulation and validation work concerning unfamiliar planes.

GILLMAN, R.E. *In defence of simulators.* Flight International, 1969, 96, 93-94.

The writer discusses the advantages of simulators under the headings (a) reliable quality checking prior to flight, (b) control over environment, (c) deep assessment of the trainee, (d) safety and (e) cost-effectiveness. He discusses simulator integrity and looks at the role of simulators in the future.

GOODIER, J.H. *Tools for the flight simulator instructor.* Proceedings of R.Ae.S. Symposium 'Flight Training Simulators for the 70s', London, England, October 1970.

Recently installed computer ancillary equipment have made it possible

1. to provide a different method of task presentation to the student, and
2. to ease the workload on the instructor, thus giving him more time for task-monitoring the student pilot.

To use this equipment advantageously, the author suggests that a library of training tasks could be stored in the computer and the tasks could be presented at will to the trainee on slides or on a CRT in a sequential training programme. A computed performance could be used as the criterion for conversion training and for the regular checks, instead of the instructor's subjective assessment. Computer programmes could be written to accommodate independent but simultaneous training for pilots and other crew members. Aural warnings could be given by the computer in cryptic language. Thus the computer will move into the decision-taking arena in the '70s.

GRIFFITHS, W.E.B. *A review of the current policy in the UK for the use of flight simulators in flight crew training and checking.* SAE 670311, 1971.

This treatise covers the history of flight simulator acceptance in the UK. Two key years are 1951 and 1960. In 1951 the Ministry of Civil Aviation – now the Ministry of Defence (Air) – allowed the use of Redifon/BOAC Stratocruiser simulators for conducting statutory instrument rating renewal tests. In 1960 the use of simulators was extended to bi-annual competency tests for pilots and flight engineers. The author explains why, with the advent of SSTs and jumbo jets, simulators will play an even larger part in pilot training and checking. He concludes that, regardless of any approval that may have been given for training or checking of the pilot's competence, the final assessment of his ability must rest with the check captain responsible. He alone can weigh up all the factors such as air training, simulator training and pilot experience. We must, however, ensure that the pilot is given an adequate tool with which to learn his job.

HALL, E.R., PARKER, J.F. and MEYER, D.E. *A study of Air Force flight simulator programmes.* AMRL TR-67-111, 1967.

#### *Object*

To gather information useful to the USAF for improving current and future simulator training programmes.

#### *Method*

The authors visited a number of pilot training units within five major US Air Commands. This report summarises their findings and sets out their recommendations. Data are presented concerning simulator training objectives, curricula, instructional methods, personnel and support factors which affect utilisation and programme effectiveness. Information relating to the acceptance of flight simulators by pilot training personnel is included.

#### *Conclusions*

Currently, simulator programmes have the following features:

1. *Objectives.* To develop pilot proficiency in systems management and emergency procedures.
2. *Content.* Local training units develop course syllabi and lesson plans. Their content is keyed to the established objectives.
3. *Training practices.* Instructor pilots have a high degree of freedom in determining specific usage of the simulator for individual students.
4. *Assessment.* Instructor judgement serves as the main criterion of proficiency.
5. *Support factors.* Simulator sections are organised for house-keeping purposes and do not become directly involved in training. Modifications to update the simulator often lag by two or three years.

#### *Recommendations*

1. *Objectives.* It should be established whether the simulator is best used as an adjunct to the pilot training process or should be used as a direct link in this process.
2. *Content.* It is desirable to ascertain what tasks should be trained in the simulator and the degree of proficiency required.
3. *Training.* An evaluation of the effectiveness of various alternative training methods and techniques is desirable.
4. *Assessment.* Methods and formats should be developed for assessing student proficiency.
5. *Support factors.* It is essential to find out which organisational forms are most effective in fusing the various components of the programme into a cohesive and effective training organisation. Maintenance and modification of the simulator should be immediate.
6. Simulator instructors should be given more training on simulator capabilities.

HAMMERTON, M. *Measures for the efficiency of simulators used as training devices.* Ergonomics, 1967, 10(1), 63-65. The difficulties of selecting suitable measures for assessing the efficiency of simulator training devices are discussed and some of the pitfalls are pointed out. Several formulae are discussed, keeping in mind what a potential user would wish to know, and some are recommended for use.

HAAS, D. and VOLK, W. *Status and development trends of simulation technology -- Its effects on the training of airline pilots.* Deutsche Gesellschaft für Ortung und Navigation, Nationale Tagung über Simulation im Dienste des Verkehrs, Bremen, W. Germany. Paper 3.4, 1975. (In German).

Digital computers are widely used for the recording of real-time simulation of rapidly-occurring events, and the replacement of large computers by several mini-computers for real-time recording is considered. The characteristics of suitable software for simulation studies are discussed and aspects of motion simulation, visual simulation, instructor aids and reliability are examined. Questions regarding the significance of modern simulators for the training of airliner pilots are investigated, taking into account safety factors, quality, environmental disturbance and economy. The characteristics of training in the simulator and in the aircraft are dealt with, emphasis being placed on the differences between European and American methods.

HAXTHAUSEN, B. *Flight training: Toward the zero hour.* Airline Management, May 1972.

The writer describes recent advances in computer, visual and motion systems in simulators and how these have contributed towards improved realism. Corresponding with this increase in fidelity, more time is being spent in training on the simulator and less in the aircraft. To illustrate this he gives a chronological breakdown of time spent training on the simulator and in the aircraft for the B707, B727 and the DC10. He concludes that achieving total simulation is a goal well within the industry's reach.

HENRY, P.H. *Subject instruction manual for the pilot performance evaluation system.* Final Report, March 1971-April 1974. SAM TR-74-40, 1974.

An automated system has been developed to assess pilot performance in a Link GAT-1 trainer. This report is an instruction manual for subjects and it explains the functions of the various controls and instruments of the GAT-1, and the test requirements. Included is a set of instruction cards describing the manoeuvres to be executed during the course of the hour-long test. Strategies for obtaining low error scores are also discussed.

HOPKINS, C.O. *How much should you pay for that box?* Human Factors Society 18th Annual Meeting, Huntsville, Alabama, U.S.A., October 1974.

The issue of prices for simulators is reported. How much should be paid depends on the purpose in, and method of, using the simulator. These factors establish the necessary items of equipment which, in turn, determine the cost and training effectiveness. Cost effectiveness has not been demonstrated for all the standard trimmings on current simulators and a simulator should not cost several times as much as its counterpart plane. The uses of simulators most directly related to human factors are man-machine interface research and crew training. Two other important applications are predicting success in training (selection) and evaluating current effects of past training (proficiency assessment). Topics treated under cost effectiveness are effectiveness as a function of training procedures, physical stimulation versus psychological stimulation, simulator fidelity and motivation, and fidelity and pilot acceptance. The incremental transfer effectiveness ratio is used as a measure of cost effectiveness. Motion and visual systems are the areas in which the most extensive engineering development is being done with the objective of increasing the fidelity of physical stimulation.

HUDDLESTON, H.F. and ROLFE, J.M. *Behavioural factors influencing aircrew response in training and research simulators.* Proceedings of R.Ae.S. Symposium 'Flight Training Simulators for the 70s', London, England, October 1970.

The speakers emphasised the simulator's value as an instructional aid rather than as a total training device. Its design should be based on:

- (a) the objectives of the training exercise, and
- (b) the needs and abilities of the student pilot.

They outlined the basic difficulties in performing training entirely in flight due to impossibility, expense or danger and they recalled some investigations into the transfer of learning. As an example of the economics of the simulator, the speakers cited a recent survey involving a group of experienced pilots converting to the DC-8. A tentative conclusion was that, for an increase of about 3.3 simulator hours, about 1.3 hours were saved in flight. While the pilots considered the simulator adequate in some respects, it did not provide total experience in handling abnormal conditions, e.g. cross-wind, take-off and landing, and landing with reduced power. The speakers mentioned the sensory cues required for good simulation. The most important of these was vision, followed by vestibular and kinaesthetic cues. With reference to training, the value of the simulator depended on its ability to elicit from the student pilot the same sort of behaviour as he would make in the flight situation. For the future the speakers suggested the following fields for research:

- (a) Using experienced pilots doing continuation training, an evaluation of the simulator's efficiency should be carried out using the ratio  

$$\frac{\text{simulator hours flown in training}}{\text{aircraft hours flown in training}}$$
 as an efficiency quotient.
- (b) The problem of simulator instructor qualifications.
- (c) The difficulty of maintaining all-round goodwill while introducing faults often enough to establish the student's minimal procedural skill.
- (d) The determination of the degree of motion required for maximum transfer of training.
- (e) An investigation of the psychological effects caused by different anti-g devices, by hypnosis and by red-out simulation.

HUFF, E.M. and NAGEL, D.C. *Psychological aspects of aeronautical flight simulation*. American Psychologist, 1975, 30(3), 406-439.

The authors discuss ground-based devices used by scientists, engineers and test pilots to evaluate current and potential aircraft systems. The characteristics of a flight simulator and its major sub-systems are considered taking into account cockpits, visual attachments and their fidelity, motion systems and their fidelity, and computer systems. Simulator validity criteria are discussed and psychological phenomena related to simulation are examined.

JEFFS, E. *Flight simulators gain in realism*. Design Engineering, 1970, September 15, 47-50.

With the increasing cost in buying and maintaining aircraft, airlines can less afford to take them out of revenue-earning service in order to train aircrew. Simulators are, therefore, being used increasingly for this purpose. Reliance on simulators for training demands a high degree of fidelity, and the necessity for greater realism has been the underlying incentive for simulator development. A major advance in development followed the availability of low-cost digital computers which, by facilitating the construction of accurate mathematical models of complex flight regimes, enlarged the number of manoeuvres that could be faithfully reproduced. More recently, attention has concentrated on the development of mechanical systems to impart representative motion cues for a greater number of situations and, parallel with this, there has been a substantial refinement in visual systems and their application to the Harrier and to various commercial aircraft.

JOHNSON, W.J. *Flight simulation and airline pilot training*. IAM R-442, Paper 1, 1968.

The author considers the role of the simulator in airline pilot training under the headings (1) Reasons for using flight simulators (2) Training considerations, (3) Part-task and whole-task simulators, (4) Performance measurement and (5) Future developments.

JOHNSON, W.J. *Desirable improvements in future airline flight simulators and associated training equipment*. Proceedings of R.Ae.S. Symposium 'Flight Training Simulators for the 70s', London, England, October 1970.

To reduce the amount of in-flight training, the speaker advocated the use of simulators for all training except route training. However, before this objective could be achieved he suggested five fields for simulator improvement, viz:

1. *Vision*. There is a need for a part-task visual practice device. This would be especially beneficial for SST and V/STOL training. Other necessary improvements are:
  - (a) A 360 degree manoeuvrability capability.
  - (b) A wider field of vision with more realistic simulation of runway and approach guidance patterns in varying visibility and weather conditions, and
  - (c) Better runway and landing lighting.
2. *Motion system*. This should provide more realistic simulation:
  - (a) Of asymmetric swing on landing and TO.
  - (b) In pitch changes during TO, overshoot, approach to stall and in air turbulence, and
  - (c) Of spatial disorientation.
3. *Flying control systems*. Instead of using a hydraulic ram to provide stiffness, synthetic control devices to

simulate "feel" should be used, i.e. a similar system to that used in the aircraft itself.

4. *Computers.* More efficient diagnostic methods should be used for fault finding or faults should be programmed out.

5. *Power supplies.* Use should be made of an automatic monitor capable of checking all supplies continuously and capable of catching fast transients.

KEEGAN, J.B. *The design of simulators as aids to instruction.* Proceedings of R.Ae.S. Symposium 'Theory and Practice in Flight Simulation', London, England, April 1976.

Emphasis is placed on the role of the simulator as an audio-visual-kinaesthetic aid used as part of an overall programme of training and checking. The need for definition of the training objectives is discussed, and these are related to specific design features of the trainee-machine and the instructor-machine interfaces. The author concentrates on facets of the instructor station and its associated computer software. Current provision of training aids are examined in the light of their use, especially by civil airlines. Specific examples are given, based on a recent survey of European and North American training facilities. Instructor skills are related to their machine-minding duties, and suggestions are made for the design of equipment to maximise training transfer while minimising instructor workload.

KNOWLES, W.B. *Aerospace simulation and human performance research.* Human Factors, 1967, 9(2), 149-159.

The many large-scale aerospace simulation facilities now available offer considerable potential for the generation of data on human performance that can be used in systems engineering design efforts. To realise this potential requires an understanding of the methodological limitations imposed by the basic characteristics of human performance, the application of efficient organisational techniques, and the development of more efficient techniques of experiment planning, design and execution.

LAMONT, J.N. *Annotated bibliography on flight simulators.* Directorate of Biosciences Research, Defence Research Board, Ottawa, Canada. Technical Report HR68 (AD 247 044), August 1960.

This bibliography is likely to be of interest to Service personnel who have responsibility for the acquisition, evaluation, and use of devices for training pilots. References to simulators used for research and aircraft design are not included.

LEWIS, O.W. *Simulation - the new approach.* Air University Review, Mar-Apr 1974, 25, 41-55.

In 1929 Link built his first flight trainer. By the beginning of World War II Link trainers were extensively used in commercial and military aviation training. Since World War II simulators have progressed from the simple mechanical machine built by Link to sophisticated computerised trainers that nearly duplicate the aircraft they represent. In the sixties simulators were mainly used to provide training in basic cockpit, instrument and emergency procedures. New developments in civil and military training are discussed.

McCLURE, R.D. and KOTTMANN, H.A. *Parallelism in commercial airline and military use of simulation.* AIAA 75-971, 1975.

The author deals with the growth in simulator use and the corresponding reduction in flying training time, the investment cost in simulators and the cost saving. The commercial airline aspect of the paper emphasises the application of Systems Approach techniques to training. The military analysis covers combat simulation, stressing such programmes as the Simulator for Air-to-Air Combat and the Advanced Simulator for Undergraduate Pilot Training.

McGREGOR, D.M. *Some factors influencing the choice of a simulator.* AGARD CP-79-70, 1971.

The author outlines some of the means by which the pilot derives motion information during flight, and the results of several simulation experiments have been presented to highlight areas in which specific simulator characteristics are required in order to obtain valid results. Much work remains before the proper simulator with just the right degree of complexity for the task to be flown can be selected with confidence. A few relevant areas for further research are:

1. The possibilities and limitations of using motion wash-out in ground simulators.
2. The development of methods to reinforce pilots' subjective assessments with measurements bearing on the effort or concentration required to perform the task in hand, and
3. The evaluation of visual resolution requirements during approach and landing and low-altitude, low-speed tasks. Night landing experiments using various illumination levels might be helpful.

It is apparent that, as the task becomes more complex, the manoeuvres become more severe, and the answers

required become more quantitative, the closer the simulator must approximate to the aircraft. Obviously a sophisticated variable stability vehicle with the proper fog simulation devices and an exactly duplicated cockpit is not always available, but one must use the choice best suited to the task in hand.

MILLER, G.G. *Some considerations in the design and utilisation of simulators for technical training.* AFHRL TR-74-65, 1974.

Current technical literature relating to simulators, trainers and the role of simulation in flight training is reviewed. Rules and principles for the cost-effective application of simulation are also included. A major finding is that fidelity can be quite low in some procedural tasks without a decrement in performance. Other studies reveal that some complex electronic equipment can be substituted by simple relatively inexpensive devices without having an adverse effect on training. In general, very few studies have been completed to validate the principles of simulation that were developed over 20 years ago.

MORAN, W.P. *Total simulation - a near future goal.* Proceedings of R.Ae.S. Second Flight Simulation Symposium, London, England, May 1973.

Visual simulation has contributed to a safer, more efficient and economical method of training commercial airline crew. The training has been to the proficiency level required to fly larger, faster, more complex aircraft. The ATA and IATA goal of total simulation in airline training is now considered to be attainable. Although there are still some desired refinements to modern digital simulators and current visual systems, it is considered that the present realism and fidelity permits complete training transfer. That transfer, however, is greatly dependent on how effectively the simulator is used and maintained. The author concludes with a histogram comparing transition training times spent by pilots in the simulator and in the aircraft for the years 1966-1972 and the aircraft types B707, B727, B747 and DC-10.

MUDD, S. *Assessment of the fidelity of dynamic flight simulators.* Human Factors, 1968, 10, 351-358.

The evaluation of dynamic simulators is considered from the standpoint of the efficiency and validity of the currently used pilot assessment techniques. A set of requirements for an ideal fidelity measurement technique is presented followed by a comparison of the two general approaches to fidelity measurement - the analytical and the empirical. A hybrid method involving the use of pilot psychomotor responses rather than verbal responses is introduced. The technique retains the subjective characteristic of rating scales but provides information of an analytic nature that is more amenable to engineering analysis. Problems involved in the development of this technique are considered.

NICHOLL, J. *The economics of the ultimate simulator.* Proceedings of R.Ae.S. Symposium 'Flight Training Simulators for the 70s', London, England, October 1970.

The aim of operators is to reduce non-revenue air time to zero but this ideal would never be achieved, since the licensing authorities would always require a pilot to demonstrate his proficiency in the air. As the cost of buying and running simulators is fast increasing, so the gap between training in the simulator and in flight would lessen and, given the fact that about two hours air time would always be required during conversion, the point could be reached where airlines would refuse to pay the price asked for simulators. The author compares the time spent and the cost of training by simulator and in flight for such aircraft as the stratocruiser, DC-7, Britannia, VC-10, B707 and B747.

NINCIC, G. and PAVICIC, D. *Use of flight simulators in aircraft accident analyses.* Proceedings of 1st Yugoslav Aerocosmonautics Conference, Belgrade, Yugoslavia, May 1973. (In Serbo-Croat).

Due to their extensive facilities for the programming of aircraft systems and navigation aids, digital flight simulators are well suited for the accurate determination of the causes of aircraft accidents. Accident analysis can be carried out along several lines, with an unlimited number of repetitions of simulated flight, for the purpose of selecting data leading to the most probable causes of an accident.

PERRY, D.H. and NAISH, J.M. *Flight simulation for research.* Journal of the Royal Aeronautical Society, 1964, 68, 645-660.

Part 1 of this paper deals with the application of simulation techniques to the study of aircraft stability and control characteristics. The equipment used at RAE for this work is described. Emphasis is placed on simulation of an "outside world" view, and motion cues. Experimental evidence of the importance of these cues when making aircraft control assessments is presented. Several examples of simulation studies into the control of conventional and VTOL aircraft are given to illustrate the type of research problems which may be tackled and the techniques used in solving them. Part 2 deals with the development, from a simple simulator used in tachistoscopic studies of attitude displays, of advanced equipment used to study an instrument system for simulated LAHS flight. This involved the concept of information flow in parallel, and visually-mediated control loops, for visual and instrument flight, and led to developments in the simulation of visual flight using tele-visual techniques and in the assessment of tracking

performance using a method of mean modulus errors. These developments allowed observation of performance of concurrent visual tasks. Flight trials confirmed simulator studies of learning effects, information capacity, and instrument to visual transition. The complete simulation scheme included ground control and autopilot facilities.

REEDER, J.P. *What's important in simulation?* 21st Flight Safety Foundation Annual International Air Safety Seminar, Anaheim, California, U.S.A., October 1968.

The author discusses simulator refinements for reducing to a minimum aircraft flight time during training. Fixed-base simulators have proved very useful in advanced vehicle research, in navigation and traffic control studies, and in procedural training. However, a high degree of interpretation by trained pilots is often required to predict the suitability of aircraft behaviour or aircraft controllability from fixed-base simulation. Consequently, the interpretation of fixed-base simulation may often be wrong. The various problems of simulation such as the need for motion (especially during critical manoeuvres), characteristics of the control system and instrumentation, and visual simulation are considered. Factors which are missing in simulation (such as pucker factor) are discussed and it is shown how these factors alter the emphasis in piloting performance in the aircraft. Although simulation cannot wholly replace training in the aircraft, used judiciously it can markedly reduce the amount of in-flight time required by the student pilot to attain proficiency standards.

REYNOLDS, P.A. *Flight simulation*. Astronautic and Aeronautics, July-Aug 1974, 12, 58-63.

The objectives of flight simulation are considered, taking into account cost-effectiveness, and training for severe emergency conditions which would be dangerous in flight. Recent progress and future trends are discussed in planning, modelling, hardware and methods, analysis and interpretation. Better cost-effectiveness data is needed to plan simulation progress. To help in modelling, new techniques for analysing flight-test data to identify aircraft parameters are being developed.

REYNOLDS, R.A., WIRTH, F.A. and MATHEWS, R.H. *Cost-effective use of flight simulation*. AIAA 75-329, 1975.

Greater use of flight simulation is saving money in to-day's difficult financial climate. A wide variety of equipment and techniques exist and careful decisions can enhance simulation cost-effectiveness. The design, training, and research and development uses of simulation are considered, with examples taken from fighter design, airline and military training, space shuttle development and other case histories. The most recent developments in simulation are described and the comparative cost of simulation and flight is considered. There is a problem as to what simulation gives the most confidence for the least money, but in many areas basic knowledge is insufficient to produce answers.

RHODES, J. *The urgent need for flight simulators for present and future aircraft*. SAE 670297, 1967.

Training requirements for the commercial subsonic jet programmes and of manned space flight have dictated rapid expansion in simulator development. A degree of realism, previously unknown, is being incorporated into simulation devices. The realisation of transfer of training to the high standard required will come with the further advancement of simulation environment, instrument presentation, six degrees-of-motion systems, acceleration inputs and real world visual presentations. Many of these are already realised and the rest are in an advanced stage of development.

RINGHAM, G.B. *Flight simulation*. Journal of the Royal Aeronautical Society, 1954, 58, 153-172.

The authors open with an historical review of simulators in use from 1910 to 1954. The economics and the training advantages of simulators are compared with equivalent aircraft types. The function and mechanism of each of the computing elements is described and the mathematical equations for aerobatic and aerodynamic operation are quoted. The authors mention how the relevant properties of the atmosphere are compensated for. There is a paragraph on boundary conditions - on and near the ground. A section on the simulation of the various types of aircraft engines follows. As regards the interior equipment, cabin pressure, the autopilot, radio aids, the instrument panel, and plotting facilities are described. Noise reproduction techniques are touched on. A short concluding paragraph deals with the instructor's console, his radio equipment and recorders. The article is well illustrated.

ROLFE, J.M. *Vehicle simulation for training and research*. IAM R-442, 1968.

This is a collection of the papers presented at a symposium held at the University of Sussex as part of the 1968 Annual Conference of the Ergonomics Research Society. The topics dealt with include several aspects of flight simulation, electric and racing car simulators, teaching machines and a discussion of the symposium papers. The treatises dealing specifically or mainly with flight simulation are:-

- |                        |  |
|------------------------|--|
| Corkindale, K.G.       | } Physiological and psychological factors influencing vehicle simulation |
| Benson, A.J.           |  |
| Johnson, W.L.          | } Flight simulation and airline pilot training                           |
| Rolfe, J.M.            |  |
| Hammerton-Fraser, A.M. | } Pilot response in flight and simulated flight                          |
| Poulter, R.F.          |  |
| Smith, E.M.B.          |  |

ROOT, R.T. *An annotated bibliography of research on training aids and training devices*. AD 637-219, 1957.

In this bibliography, special consideration has been given to the use of training aids and training devices by the military services. Reports and books from psychological, military and educational literature are included e.g. abstracts from U.S. Armed Forces publications, the American Psychological Association and other American professional journals, and publications of the British and Canadian Governments. Classified information is not included.

ROSCOE, S.N. *Effective and economical simulation in the design and use of aero-systems*. Interim Report. ARL 75-8/AFOSR 75-3, 1975.

This paper is an edited version of a 1975 talk presented at a conference on the simulation of aero-systems co-sponsored by the USAF Office of Scientific Research and the USAF Flight Dynamics Laboratory. The characteristics which simulators must possess for effective and economical use are shown experimentally to differ as a function of their application, whether in engineering research, pilot performance assessment and prediction, or in training. Issues in the design and use of training simulators involve the cost-effectiveness of motion systems, visual systems and performance measurement systems.

SCHOHAN, B. *Human factors recommendations for the design of cockpit procedures trainers*. WADC TR-56-527, September 1958.

This report is intended to help design engineers by presenting first, a discussion of the cockpit procedures trainer's role in training and second, a set of human engineering recommendations pertinent to the design of such trainers for fighter-type jet aircraft.

SCHULZ, U. and SEELMANN, H. *Views regarding the validity of results from simulation testing in comparison with the results from actual flight test*. NASA TT-F-15172, 1973.

A comparison of the validity of results obtained by flight simulation with results obtained from actual flight tests is presented. The background for the development of the simulator is discussed. The techniques for conducting the simulation are outlined. Examples of flight simulation operations are developed. Results of the comparison indicate good correlation between simulation and flight test data.

SINACORI, J.B. *Validation of ground-based simulation*. AHS Preprint, 362, 1969.

This is a study of various kinds of simulators to determine their ability to produce data representative of visual flight. Five simulations of a small jet-lift V/STOL aircraft using the same pilot are reported. The resulting data is compared with flight results using the same aircraft and pilot. The simulators used different displays, motion modes and instrumentation, and the results are discussed in the light of the characteristics of each simulator and the aircraft. The precision hover and the lateral quick start and stop manoeuvre are studied in detail.

SMITH, A.H., BACON, E.A.H., COOK, T.W. and MAEERS, S.P. *The problem of the utility of the flight simulator*. Defence Research Establishment, Toronto, Canada. DRML 154-33-67-1, 1954.

This treatise consists of a general survey of the simulator field with the object of providing the RCAF with useful information for conducting a simulator programme and setting up a fund of data for use in research on simulators. The topics discussed include their origin and current status, their evaluation, the development of a programme, and major research questions. The main problem areas in the use of simulators are indicated.

SMODE, A.F. *Recent developments in instructor station design and utilisation for flight simulators*. Human Factors, 1974, 16, 1-18.

The author discusses the impact of computer assistance on the capability for structuring and controlling synthetic flight training and he examines the instructional potential of simulators currently on-line or in the development stage. He describes innovations in instructor station design.

TARDY, J. *Methods used for optimising the simulation of the Concorde SST using flight test results*. AGARD CR-172, 1975.

The extensive facilities provided by simulators and their associated computers were widely used in the design of Concorde. Early development work was done on a fixed-base simulator and more sophisticated simulators were used as work progressed. The present simulator has been used for development studies for the aircraft and its systems, handling qualities, flying controls, pilot aid failures, flight test preparation, crew training and workload studies, flight and failures investigation in extreme atmospheric conditions, aircraft certification studies and the introduction of the aircraft into congested air traffic conditions.

VALVERDE, H.H. *Flight simulators. A review of the research and development.* AMRL TR-68-67, 1968.

The author reviews R and D work carried out on simulators and trainers for the period 1949-1968. The work was sponsored by US military and Government agencies and is unclassified. The report does not deal with mathematical models or space-flight simulators. The topics covered include use and evaluation processes, transfer of training, visual and motion simulation, and computer simulation. Over 200 synopses of pertinent experiments are included. The treatise is well illustrated.

WILCOXON, H.C. and WEBSTER, J.C. *Survey utilisation of fleet-type Operational Flight Trainers (OFTs).* SDC 999-2-2, 1954.

To provide information on the use and adequacy of design of OFTs, interviews with trainer instructors and pilots, and check-list questionnaires were used together with personal observations of the device under training conditions at various installations. The authors present their findings and a comprehensive discussion of specific issues in OFT design.

WIRTH, F.A. *Flight simulator development in parallel with aircraft flight test.* SAE 720858, 1972.

In order to assure delivery of a crew training simulator while flight testing is incomplete and several months ahead of the delivery of its counterpart aircraft, new and unusual methodology must be applied. Such methodology, called positive interface management, has been developed and successfully applied to the DC-10 programme by American Airlines. The author details how this has been done. When effectively executed, safety is enhanced, money is saved, and transition training is facilitated. The author has shown how, by considerate use of simulators, the time spent training in the aircraft has been whittled down. To illustrate this, he cites comparative simulator/aircraft training times for the B707, B727, B747 and the DC-10 planes.

WOODEN, W.A. and COWELL, J.D. *Optimising the use of the flight simulator.* Proceedings of Second R.Ae.S. Flight Simulation Symposium, London, England, May 1973.

To make the best use of simulators, the authors considered the following factors of prime importance:—

1. The setting up of more formal arrangements for the training and certification of airline instructor/examiners with emphasis on the variant instructional techniques used during simulator training.
2. Exploitation of the different and advantageous environment of the simulator for conversion courses by the introduction of programmed learning, automated demonstration and manoeuvres replay.
3. Increased use of systems rigs, part-task trainers, and photographic models so as to use the simulator to a greater extent in its dynamic role.
4. For the purpose of continuation training/checks, all possible steps should be taken to provide total flight environment simulation. Simulation has reached a high degree of sophistication with the combined use of digital and analogue techniques. Careful consideration should, therefore, be given to the retention of this fidelity and the associated maintenance techniques.
5. Investigation should be made into the additional use of the computer to drive system rigs and classroom displays at the same time as driving the simulator.

## TRAINING

ADAMS, J.J., HUFFORD, L.E. and DUNLOP, J.M. *Part- versus whole-task learning of a flight manoeuvre*. NTDC 297-1, June 1960.

Cockpit procedures trainers can be effective training devices but cautions in their use are suggested. They can be used unequivocally in training any procedural sequence such as engine start which does not require concurrent flight control of the aircraft. For airborne normal and emergency procedures it is recommended that training in a cockpit procedures trainer be followed by a nominal amount of whole-task practice. For some procedures it might be safe to do this in the aircraft. An operational flight trainer could provide this integrative practice for all procedures and, of course, be perfectly safe. A cockpit procedures trainer does not yield an accurate measure of a pilot's proficiency in procedures. The score in procedures performed in the part-task trainer is a spuriously high index of proficiency in the whole task where concurrent flight control is required.

ANGELL, D., SHEARER, J.W. and BERLINER, D.C. *Study of training performance evaluation techniques*. NTDC 1449-1, October 1964.

This report discusses performance evaluation in the training environment, specifically in training situations involving the use of simulators and other complex devices. The important variables involved in developing a system of performance evaluations are seen as (1) types of behaviour, (2) types of measures or mensural indices, and (3) types of instruments for recording performance. Factors relating to these variables are discussed and some of their inter-relationships are delineated. A selected bibliography of 58 items is included.

BENSON, J.A. and DE TALLY, W.A. *Air navigator training system design*. Institute of Navigation 25th Anniversary Year Meeting, USAF Academy, Colorado Springs, Colorado, U.S.A., July 1970.

The authors discuss the design definition and the selection of a configuration for an airborne trainer and ground simulator. The Undergraduate Navigator Training System was used as an example. The similarities of requirements, functions and man/machine interface allow the development of configurations for the airborne trainer and ground simulator as a parallel design effort. Training requirements are categorised into crew, environment and equipment parameters presented as they are represented on board the airborne trainer and within the ground simulator. Student, instructor, and operator task flow and individual assignments are described and related to the airborne trainer and the ground simulator.

BEUTLER, G.C. *Training airline flight crews*. IEEE Transactions on Education. E-15, 129-133, 1972.

The beneficial effects of improved crew training are discussed. Emphasis is placed on safety and on the application of simulators. Training programmes are outlined which makes it possible to cut the training period from up to 56 days to under 30 days.

BLAIWES, A.S., PUIG, J.A. and REGAN, J.J. *Transfer of training and the measurement of training effectiveness*. Human Factors, 1973, 15, 523-533.

Transfer of training research has been conducted on actual training systems to determine:

1. The effectiveness of present training,
2. Whether the training can be improved, and
3. How the training might be improved.

The present paper includes some major methodological and analytical considerations in performing this research - the experimental and descriptive models to use in investigating and expressing transfer, cost effectiveness evaluations, and aspects of the training system to be included in the study. A number of conclusions are derived from the transfer research and some popular research themes are identified. Desirable features for an applied research programme for military training purposes are presented. Problems arising from the use of the transfer of training model are traced to operational constraints placed on experimental manipulation and control, and to the inadequacy of performance measurement systems. Solutions to these problems are discussed. One solution provides alternate methods to the transfer of training model for evaluating the effectiveness of a training system. Another approach recommends the employment of laboratory simulations of training or operational situations for transfer research.

BOWEN, H.M., BISHOP, E.W., PROMISEL, D. and ROBINS, J.E. *Study, assessment of pilot proficiency*. NTDC 1614-1, 1966.

### *Purpose*

The aim was to assess the role of the Operational Flight Trainer (OFT) in a US Navy squadron teaching qualified pilots to fly A4 aircraft prior to joining Fleet operations. The specific aim was to find appropriate objective scoring devices and associated procedures that could be used in future OFTs to enhance the training experience of student pilots and to afford a reliable basis for assessing pilot proficiency.

### *Method*

Twenty pilots took part. They were matched to form an experimental group and a control group. The experimental class had feedback of scoring information during training. The control group were trained by orthodox methods.

The performance of both groups was compared to find if feedback facilitated training. Data related to the history of the pilots, squadron scores and measures of proficiency during field mirror landing practice and carrier qualification was also used.

#### *Conclusions*

1. Augmented feedback in the form of objective scores tends to heighten performance.
2. OFT scores of proper sequencing of procedures, control of aircraft to prescribed settings, and response time to unexpected situations are independent measures of pilot skill.
3. These scores are predictive of proficiency at landing the aircraft and they indicate that OFT performance can provide valid pilot proficiency assessment data. However, the predictive relationship from measured OFT performance to actual flight is not simple and seems to depend on there being an adequate correspondence between the requirements imposed on the student in the OFT and in flight.
4. It is important for the student in the OFT to experience the plurality of events that can occur in real flight missions. Scores extracted during performance of such missions or mission segments will indicate the degree to which the student has acquired the necessary skills and the ability to deploy them effectively and appropriately against actual flight requirements.

BOWEN, H.M., HALE, A. and KELLEY, C.R. *Tracking training V: Field study of the training effectiveness of the general vehicular research tool*. NTDC 955-1, 1962.

#### *Object*

The purpose was to find the effectiveness of a general vehicular research tool (GVRT). This device embodies the concept that the skill associated with the control of a given vehicle is a general one which can be developed to a large extent with a training system not specifically representing any single vehicle.

#### *Method*

The experiment was in two parts viz,

1. a comparison of two groups of Aviation School students. One group had practice on the GVRT in addition to the regular training curriculum, the other did not have GVRT training.
2. a comparison of the performance of two groups of Submarine School students on a simulator after one group had received GVRT training and the other trained on the simulator itself.

#### *Conclusions*

1. Aviation School Students.

The group who received a portion of their training on the GVRT was 11% more proficient than a group without such training in terms of a flight rating measure.

2. Submarine School Students.

The group given training on the GVRT did about one-half as well as the other group in controlling the simulator. The results are discussed and recommendations for equipment modifications and further experimental use are presented.

BROWN, E.L., MATHENY, W.G. and FLEXMAN, R.E. *Evaluation of the School Link as an aid in teaching ground reference manoeuvres*. SDC 71-16-7, 1970.

This is a preliminary report about the efficacy of using a flight trainer for teaching ground reference manoeuvres. Analysis showed that errors made while learning to land a light aircraft could be reduced by prior instruction in the Link trainer. A discussion is presented concerning instructional techniques when using contact trainers, and the importance of determining the reliability of performance records.

BROWNING, R.F. and RYAN, L.E. *Training analysis of P-3 replacement pilots and flight engineer training. Final Report*. NAVTRAEPICEN TAEG-10, 1973.

This report deals with pilot and flight engineer training at the Replacement Squadron level. It presents the results of an assessment of the training effectiveness of the Operational Flight Trainer and the Cockpit Familiarisation Trainer, a field tryout of an experimental synthetic and flight syllabus for P-3 (four turbo-prop engines) replacement pilot training, an economic analysis of the potential savings realisable from an improved instructional strategy, and an analysis of the current flight engineer training syllabus. The requirement for a six-degree-of-freedom motion platform and a visual system is discussed as are additional tasks that may be trained in this simulator.

CARO, P.W. *Equipment-device task commonality analysis and transfer of training*. HumRRO TR-70-7, 1970.

Using a modified 1-CA-1 Link device employed in US Army rotary wing instrument training as a vehicle for this research, procedures were developed for an equipment-device Task Commonality Analysis (TCA). Information derived through the TCA was then used to predict the occurrence of both positive and negative transfer of training from the device to the operational equipment. On the basis of these predictions, characteristics of training programmes for use with the device in rotary wing instrument training were stated.

#### *Conclusions*

The systematic comparison of task elements involved in performance in training devices and operational equipment could provide an objective basis for development of effective training programmes. The TCA procedures developed in this study can be used wherever training programmes are developed which include training devices not optimised

for use in the programmes. Such situations occur wherever existing devices are modified to meet new training requirements or when "off the shelf" devices are procured for use in specialised training programmes. In the case of the I-CA-1 it was concluded that little task commonality exists between it and the operational equipment. Predominantly negative transfer of training was predicted from its use.

CARO, P.W. *An innovative instrument flight training programme.* HumRRO PP-16-71, 1971.

*Equipment*

A Link GAT-2 trainer and a Baron aircraft (T-42, light twin-prop).

*Summary*

An innovative flight training programme, its development, and administration are described. A GAT-2 trainer was used in a twin-engine transition and instrument training course. The main features of the programme include redefinition of the flight instructor's role, an incentive award system, proficiency-based advancement, full mission training in the GAT-2, continuity of training between the GAT-2 and the T-42 aircraft and use of manoeuvre performance records to control trainee progress. It was found that training flight time was reduced by 40% using this programme.

CARO, P.W. *Aircraft simulators and pilot training.* Human Factors, 1973, 15, 502-509.

Traditionally, simulators have been less important for training than have aircraft but they are currently emerging as primary pilot training vehicles. This new emphasis is an outgrowth of systems engineering of flight training programmes, and a characteristic of the resultant training is the employment of techniques developed through applied research in a variety of training settings. These techniques include functional context training, minimising over-training, effective use of personnel, use of incentive awards, peer training and objective performance measurement. Programmes using these and other techniques, with training equipment ranging from highly realistic simulators to reduced scale paper mockups, have resulted in impressive transfer of training. The conclusion is drawn that a proper training programme is essential to realising the potential training value of a device, regardless of its realism.

CARO, P.W. *Some factors influencing transfer of simulator training.* Proceedings of R.Ae.S. Third Flight Symposium, London, England, April 1976.

Based upon his observations and on a perusal of training literature, the author discusses factors influencing training transfer. He draws attention to factors which have been found to have a depressing influence on the effectiveness of training. These include device design, the training programme, the attitudes and expectations of instructors and programme administrators, device maintenance and appearance, and the rewards and penalties used in the administration of simulator training. Emphasis is placed on the cost-effectiveness of training through simulation.

CARO, P.W. and ISLEY, R.N. *Helicopter trainee performance following synthetic flight training.* HumRRO PP-7-66, 1966.

The aim was to find if the use of a helicopter trainer would improve the subsequent flight performance of trainees at the US Army Primary Training Helicopter School. Two groups were trained to "fly" a captive helicopter mounted on a ground effects machine. It was found that the device-trained group were significantly less likely to be eliminated from subsequent primary training for reasons of flight skills deficiency. Furthermore, measures of performance during primary training indicated that the device-trained group flew solo sooner and obtained better flight grades than did the control group.

CARO, P.W., ISLEY, R.N. and JOLLEY, O.B. *The captive helicopter as a training device: Experimental evaluation of a concept.* HumRRO TR-68-9, 1968.

*Equipment*

The Whirlymite Helicopter Trainer consists of a small one-man helicopter attached to an independently powered Del Mar Ground Effects Machine by an articulated linkage assembly. This configuration allows the captive helicopter (within limits) to translate, to climb to a hovering altitude and to rotate. A novice is able to use this device to practice contact flight manoeuvres.

*Method*

Two experimental programmes of instruction were developed for the device and these were administered to two groups of 33 WO candidates during the preflight training phase of the WO Rotary Wing Aviator Course. Two control groups received no device training. The experimental training consisted of 3¼ to 7¼ hours of practice on a progressively more difficult series of tasks designed to develop proficiency in the helicopter hovering manoeuvres taught during early flight training. Flight performance of the experimentally trained WO candidates and their control counterparts during the 85 hour primary training programme provided the criterion measures.

*Conclusions*

The use of this device could result in:--

- (a) A significant reduction in rates of elimination from subsequent helicopter flight training.
- (b) Significant improvements in trainee performance early in flight training.
- (c) Prediction of proficiency level during subsequent helicopter flight training.

Instructors using such devices need not be required to be proficient in the helicopter used for subsequent flight training.

CARO, P.W., ISLEY, R.N. and JOLLEY, O.B. *Research on synthetic training: Device evaluation and training programme development.* HumRRO TR-73-20. 1973.

Two studies were conducted to evaluate a fixed-wing instrument procedures training device (a twin-engine GAT-2) and to develop a training programme for use with this device. In the first study, a group of trainees at the U.S. Army Aviation School who received instrument training in the GAT-2 were compared with a control group who did not receive synthetic training. The difference in inflight performance on a Baron (T-42, twin-prop) light aircraft as measured by checkrides indicated that men trained on the GAT-2 tended to perform more satisfactorily than the control group. The second study was concerned with the development and evaluation of an instrument flight training programme designed for use with the GAT-2. Use of this programme gave a substantial reduction in the flight time required to attain twin-engine transition and the instrument flight objectives of the course. It appears that the training concepts used in developing the training programme using the GAT-2 have application not only to other flight training courses for both fixed and rotary wing aircraft but in other programmes using training devices.

CARO, P.W., JOLLEY, O.B., ISLEY, R.N. and WRIGHT, R.H. *Determining training device requirements in fixed wing aviator training.* HumRRO TR-72-11, 1972.

A study of all fixed wing pilot training programmes at the US Army Aviation School was conducted for 1968 to find whether training might be made more effective through greater use of synthetic flight training equipment and, if so, to specify the main characteristics of appropriate equipment. Secondary objectives were to assist in developing low cost devices for one course and to determine the probable cost-effectiveness of a commercially available device in another. A method was developed which identified specific and differential needs for synthetic equipment in each course and determined suitability of existing equipment to meet those needs. A generalisable, systematic method for determining requirements for synthetic training equipment in existing training programmes resulted.

CARROLL, J.J. and ZEISMER, R. *SST training programme considerations.* SAE 670307, 1967.

The development of training programmes for ground and flight personnel for system operation of the US SST is a responsibility shared by the Office of SST Development, the FAA, the airframe and engine manufacturers and the airlines. Current engineering development, experimental and flight simulators are providing the basis for definition of optimum operating procedures, standards, identification of efficient instructional procedures and for an eventual safe and economic means to evaluate crew member capabilities and proficiency. Closer co-operation between flight operations personnel and simulator design engineers is essential if effective SST training programmes are to be achieved.

CHARLES, J.P., JOHNSON, R.M. and SWINK, J.R. *Automated flight training (AFT) GCI/CIC air attack.* Final Report Feb 1972-Jul 1973. NAVTRAEQUIPCEN 72-C-0108-1, 1973.

A feasibility demonstration of the application of automated-adaptive training techniques for air-to-air intercept training in a flight simulator was conducted. The training task included three phases:

1. A climb task under GCI/CIC control.
2. An attack phase under RIO control and a steering dot display, and
3. A descent phase also under GCI/CIC control.

Sidewinder-type missile intercepts including head-on, forward-quarter and beam runs were incorporated into a training syllabus. Atmospheric turbulence, aircraft configuration and bank angle were used as adaptive variables. Performance was objectively measured for each phase and the syllabus was restructured (on line) based on that performance.

CREELMAN, J.A. *Evaluation of approach training procedures.* U.S. Naval School of Aviation Medicine, Naval Air Station, Pensacola, Florida U.S.A. Technical Report AD 89-997, October 1959.

The training effectiveness of a contact approach trainer was evaluated under routine training conditions within the framework of US Navy primary flight training. Two sets of subjects took part in the assessment viz.,

1. an experimental group who were given instruction in the approach trainer before attempting landings in the aircraft, and
2. a control group who did their training in the aircraft.

#### *Conclusion*

The results indicate that the experimental group obtained (statistically) significantly higher ratings on approaches, needed fewer practice landings during the pre-solo stage, and had fewer unsatisfactory check flights than the control group.

CROOK, W.G. *Experimental assessment of ground trainers in general aviation pilot training.* FAA ADS-67-5, 1967.

The author compared the effectiveness of different types of trainers when used in a private pilot training programme. His objectives were:-

1. To determine standards for identifying trainers in which instruction would be acceptable toward pilot certification requirements, and
2. To determine how much time in a trainer might be substituted for flight time.

#### *Conclusions*

No specified design or operational standards for trainers are recommended. The average total airplane time required to reach private pilot proficiency was reduced by 16%. A 15% substitution of trainer time for airplane instruction time is recommended in the approved 35 hour flight curriculum requirement.

DACHERY, M. and BRANDET, C. *The training centre for naval aviation navigation*. Navigation (Paris), 1975, 23, 310-323, In French.

The author outlines the kind of training carried out at this centre. The training cabin (which includes an astronomical simulation in addition to the conventional "outside world" view), instructor station, computer system and computerised training programmes are described. The computer programme simulates aircraft flight and aircraft intrusions.

DANNESKJOLD, R.D. *Objective scoring procedure for operational flight trainer performance*. SDC 999-2-4, 1956.

An objective method of grading student performance in flight trainers, the Basic Instrument Check, is described in detail and is discussed with respect to its reliability and its validity in predicting pilot proficiency. Validity coefficients are based on the performance of 53 students. Reliability coefficients are based on the judgements of 50 observers.

DEMAREE, R.G., NORMAN, D.A. and MATHENY, W.G. *An experimental programme for relating transfer of training to pilot performance and degree of simulation*. NTDC 1388-1, June 1965.

The Universal Digital Operational Flight Trainer (UDOFT), programmed to simulate a high performance single-engine jet fighter, was used for an initial pilot performance study. Six manoeuvres were employed in conjunction with real-time simulation of in-flight piloting tasks in a F-100A cockpit. The results of this study and of earlier investigations with the UDOFT provided a basis for planning a series of pilot training experiments. The methodology, rationale, and design of these experiments were oriented toward effective use of the UDOFT to establish the extent to which reductions in the degree of simulation affects piloting performance and the amount of transfer of training.

DOUGHERTY, D.J., HOUSTON, R.C. and NICKLAS, D.R. *Transfer of training in flight procedures from selected ground training devices to the aircraft*. NTDC 71-16-16, September 1957.

The idea was to test the relative training effectiveness of four devices for training pilots in normal and emergency procedures in new aircraft. A photographic mock-up of the cockpit, a partly activated trainer, a flight simulator and the combination of a part-task (procedures) trainer and time-shared tracking task were tested by equivalent groups.

#### Conclusions

1. Each device made a significant contribution to learning in-flight procedures.
2. An operational flight trainer and a procedures trainer made equally effective contributions to training, equal to that in the aircraft itself.
3. Training on procedural tasks alone did not adversely affect performance on flight tasks when both were simultaneously required in the aircraft.
4. Time-sharing while learning procedures did not aid in-flight performance on flight and procedure skills.

DUNFORD, M.J. *The continuing case for aircraft training*. Aircraft Engineering, 1976, 48, 11-13.

The author emphasises the cost benefit of simulator, as opposed to aircraft, training by comparing the hourly operating cost of certain aircraft with their counterpart simulators. However, he points out that the base for cost comparison has shifted and is now centred on the economics of one type of simulator as against another. For example, the multi-cockpit simulator is extremely cost-effective in that a large number of pilots can be trained simultaneously. This method has proved successful where the task is basically one of initial, conversion or continuation training. For full-mission simulations, the need for individual simulators is evident. Advances in digital radar systems have greatly improved simulator realism and total fidelity.

ELLIS, N.C., LOWES, A.L., MATHENY, W.G. and NORMAN, D.A. *Pilot performance, transfer of training and degree of simulation: III Performance of non-jet-experienced pilots versus simulation fidelity*. NTDC 67-C-0034-1, 1968.

The objective was to determine the feasibility of degraded levels of simulation fidelity using non-jet pilots "flying" an operational flight trainer. Fidelity was varied by incorporating coefficient changes into the aerodynamic equations of flight such that rigid coefficients and least squares approximations served as experimental conditions and flexible coefficients served as the control.

#### Conclusion

Feasibility of rigid coefficients used in the aerodynamic equations during simulated training manoeuvres was demonstrated but the use of least squares approximations was doubtful.

ELLIS, N.C., LOWES, A.L., MATHENY, W.G. and NORMAN, D.A. *The feasibility of using an adaptive technique in flight simulator training*. Ergonomics, 1971, 14, 381-389.

The authors explored the feasibility of using an adaptive technique in simulator training to improve piloting skills. An operational flight simulator was used to simulate a jet fighter aircraft. Eighteen non-jet pilots were assigned to two groups and they had equivalent amounts of practice in maintaining a constant altitude programme during simulated turbulence. One group trained using an adaptive technique and the other trained using conventional methods. The hypothesis was that an adaptive technique is feasible if adaptively trained pilots are more proficient than conventionally trained ones when "flying" in simulated turbulence. Resulting data supported this hypothesis.

ELLIS, N.C., LOWES, A.L., MATHENY, W.G., NORMAN, D.A. and WILKERSON, L.E. *Pilot performance, transfer of training, and degree of simulation: II Variations in aerodynamic coefficients*. NTDC 1889-1, May 1967.

This is the third report in a study programme dealing with pilot performance, transfer of training, and degree of simulation. Transfer of training studies were conducted to determine the training feasibility of simulations in which aerodynamic coefficients were varied. Experiment I incorporated coefficient changes in the longitudinal mode, Experiment II in the lateral mode, and Experiment III in the combined longitudinal and lateral modes.

#### *Conclusions*

The feasibility of these reduced simulations as conditions for training was demonstrated.

#### *Recommendation*

Further study using other pilot populations, flight regimes, manoeuvres, and simulator capabilities to determine full implications of these findings should be undertaken.

FLEXMAN, R.E. *Advanced training concepts in simulation*. Proceedings of Twenty-first Flight Safety Foundation Annual International Air Safety Seminar, Anaheim, California, U.S.A., October 1968.

The author discusses new training concepts which will permit improvements over present training programmes. The basic objectives of flight training are examined and the required changes in present training programmes are outlined. It is then shown how these changes can be implemented by new advanced training concepts based on the use of digital simulators. A list of manoeuvres is given which have been analysed for programming on the TWA 707 simulator.

FLEXMAN, R.E. and LATHAM, A.J. *Use of a contact flight simulator in training of basic student pilots*. HumRRO RN-Pilot-52-1. 1952.

Ten non-pilot airmen acted as students in the training of ten flight instructors. This research note presents information on student performance which, while incidental to the primary purpose of the exercise (instructor training) and unsuitable for analysis, contains interesting implications for training research. A large proportion of the pre-solo manoeuvres and skills appeared to have been learned in the P-1 trainer used by this highly selected sample of students. The extent to which these skills can be learned by regular cadet samples, what other skills can be acquired, and the best combination of trainer and aircraft time are topics worth investigation.

FLEXMAN, R.E., ROSCOE, S.N., WILLIAMS, A.C. and WILLIGES, B.H. *Studies in pilot training: The anatomy of transfer*. ARL Aviation Research Monographs, 1972, 2(1), 1-87.

This attempt to evaluate the pattern of transfer of training from the SNJ Link trainer to retraining in the SNJ aircraft was done in two parts.

*Experiment 1 - Contact Flight* The performance of 6 students who received instruction both in the trainer and the aircraft were compared with 6 students trained only in the aircraft.

*Experiment 2 - Instrument Flight* The experimental routine was similar to EXPT 1, but here the cockpit windshields both in the trainer and the aircraft were opaque. Two fresh groups of students (6 per group) took part. They wore blue goggles during training.

#### *Findings*

Higher transfer occurs with procedural tasks than with psycho-motor tasks because the former are less adversely affected by the imperfect simulation of such dynamic factors as physical motion, visual and kinesthetic cues, and control pressures. This does not mean that effective transfer of procedural tasks requires less fidelity in simulator design. Lack of procedural fidelity results in the transfer of incorrect responses, thereby yielding negative transfer to the performance of correct procedures in flight.

FLEXMAN, R.E., TOWNSEND, J.C. and ORNSTEIN, G.N. *Evaluation of a contact flight simulator when used in a USAF Primary Pilot Training Programme Part 1 - Overall effectiveness*. AFPTRC TR-54-38, 1954.

This study indicated that the efficiency of instruction in the Primary Pilot Training programme may be greatly improved by the use of a contact simulator for training. Simulators with higher fidelity have been developed since the design of the movable, vacuum-operated simulator used here. These more recent simulators (all fixed-base) do not, however, provide external visual cues. The results suggest that consideration should be given to the development and evaluation of a visual system for contact simulation in fixed-base simulators.

FRICK, R.K. *Quantitative effects in the use of simulators for training fighter pilots*. AIAA 72-161, 1972.

Analysis of historical combat data indicates that the fraction of fighter pilots killed increases as the number of decisive air-to-air combats increases. This could be as a result of two groups of pilots being present, viz. a superior group represented by those who learn from experience and (2) an inferior group represented by those with no learning. A proposed plan for training, based on this hypothesis, is presented. Using a mathematical model based on renewal theory, the author shows how a training programme using simulators can have a significant payoff in terms of improved force effectiveness and reduced pilot losses.

FRISBY, C.B. *Field research in flying training*. Occupational Psychology, 1947, 21, 24-33.

The Director of the National Institute of Industrial Psychology gives an account of his advisory work with the Air Ministry now the Ministry of Defence (Air), at the Central Flying School. He describes some of the work done and

the criteria used in assessing flying skills. He illustrates the special difficulty involved in flying training research by giving an account of an experiment carried out to evaluate a landing trainer.

FULGAM, D.D., REID, G.B., WOOD, M.E. and McLEOD, I.N. *Design and application of a part-task trainer to teach formation flying in the USAF Undergraduate Pilot Training*. AIAA 73-935, 1973.

A part-task trainer has been developed that provides a safe economical means to condition student pilots to the high performance formation flight environment prior to actual flight. This Formation Flight Trainer (FFT) provides the pilot with a wide-angle display of a T-38 (supersonic, twin-jet) lead aircraft that is continuously variable in relative bearing, relative altitude and range. Students were provided varying amounts of practice in both the trainer and the T-38 aircraft and then comparisons were made to define the trainer contributions to the formation task. Initial trials indicate that the FFT makes a significant contribution to early skill acquisition in formation flying.

GABRIEL, R.F. and BURROWS, A.A. *Improving time-sharing performance of pilots through training*. Human Factors, 1968, 10, 33-40.

Sixty attack pilots were matched on flying experience to form two groups - a control group and an experimental group. Using simple, generalised but adaptive simulation devices, the experimental group was trained over an eight week period in display reading and in hazard detection. The control group received only instructional training. A comparison of the two groups in a simulated flying task showed that hazard detection was improved by device-training without any degradation in other flying tasks.

GERATHEWOHL, S.J. *Fidelity of simulation and transfer of training: A review of the problem*. FAA AM-69-24, 1969.

There are a variety of simulators currently available and providing valuable tools for research, training and proficiency determination. They range from simple trainer type devices useful for learning specific tasks to very sophisticated ground facilities, and aircraft used for crew training under simulated environmental and operational conditions. The various perceptual phenomena and performance modes observed indicate that it is not the physical similarity of the devices but psychological, physiological and operational realism which determine fidelity in simulation. In general, the amount of transfer of training appears to be closely related to the degree of fidelity provided.

GIBINO, D.J. *A systems analysis approach to the design of aircrew training equipment*. AIAA 68-274, 1968b.

The author develops an integrated training system for aircrew. The impetus for taking a systems analysis approach to training is based on an examination of the mission simulator. It is shown that the use of increasingly complex simulators is directly related to decreasing system effectiveness and that the use of part-task trainers can be more cost-effective than the use of multi-purpose devices. The important system variables are (1) training requirements, (2) student population group, (3) student training rate, (4) facility operating rate, (5) component utilisation factor, and (6) procurement and operating costs. The overall systems analysis problem is postulated in terms of operations research. The benefits of operating the systems concept are, (1) more effective usage of equipment at relatively lower cost, and (2) a high degree of training programme flexibility.

GIBSON, J.H. *Optimised flight crew training - a step toward safer operations*. AIAA 69-771, 1969.

The author sets out the results of tests on forty captains trained under a new sequence of simulator training, local take-off and landing practice in the aircraft, and closely supervised line experience. Data was obtained through manoeuvre evaluations by FAA and American Airline check pilots, student questionnaires and instructor/check pilot interviews.

#### *Conclusions*

The results indicate that safety improved for all phases of training and line operations. Aircraft training times (including type rating) were reduced to just over 5½ minutes. Student pilots could be trained to a level of proficiency in the simulator that would assure satisfactory performance in the aircraft.

HASS, W.-D. *A study of the cost benefits of using flight simulators for crew training*. DGLR Anthropotechnicians Committee, 16th Meeting, Frankfurt, Germany, November 1974. (In German).

An analysis of the economics of training aircrew using flight simulators is presented. Two B-707 training programmes were compared as to training times and costs. One of the simulators used (Redifon) was recommended for its fidelity and for its cost-effectiveness.

HALL, E.R. and CARO, P.W. *Systems engineering of Coast Guard Aviator training*. HumRRO PP-17-71, 1971.

Reference is made to the part flight simulators play in Coast Guard Aviator training.

HAVRON, M.D. and BUTLER, L.F. *Evaluation of training effectiveness of the 2-FH-2 helicopter flight trainer research tool*. NTDC 1915-00-1, 1957.

This evaluation was conducted to determine the effectiveness of Device 2-FH-2 helicopter flight trainer research tool.

The device consists of a unique type of visual display, a cockpit with activated instruments and controls, and a generalised flight system computer. It was originally constructed to determine the feasibility of using an internal non-programmed point-source-of-light projection system to create the illusion of three dimensional space on a curved projection screen. The flight computer is designed to approximate in a general way the flight characteristics of the Bell HTL4 helicopter. The evaluation examined the device's usefulness in the initial training stages and the attendant problems when transferring to an operational helicopter. The findings indicated no particular advantages in this type of training and, in fact, some negative effects were noted. Some recommendations for analysing these negative results are indicated.

HULL, R.E. *Navigator training analysis*. Institute of Navigation 25th Anniversary Year Meeting, U.S. Academy, Colorado Springs, Colorado, U.S.A., July 1970.

The author cites the methods and results of a study directed at deriving a combination of aircraft and simulators which would best accomplish trainer tasks for the USAF Undergraduate Navigator Training System. Emphasis is placed on developing a rationale for measuring training effectiveness. The methodology is based on the application of a family of student learning curves which were derived from grade data collected at Mather A.F.B. Cost trade-offs provide the optimum average grade levels to be achieved for each ground trainer and simulator mission prior to transferring students to flight missions. The results show that the present system has a well-balanced mix of aircraft and ground trainers from the standpoint of cost effectiveness, but a modernised system would provide improved integration of ground and flight training, producing navigators better qualified for future environments.

ISLEY, R.N., CARO, P.W. and JOLLEY, O.B. *Evaluation of synthetic instrument flight training in the Officer/Warrant Officer Rotary Wing Aviator Course*. HumRRO TR-68-14, 1968.

This research was an experimental evaluation of the modified 1-CA-1 devices as they were used at the US Army Aviation School during 1967. Trainees who received the prescribed training in these devices were compared with other trainees who received only half as much training, or none at all. The differences in flight performance among groups, if any, would be indicative of the training contribution of the device. Measures of the relative performance of the three groups on the end-of-phase checkride constituted the major criteria for determining the value of the synthetic training received. Other criteria used were grades during training, time to checkride, and checkride grades. Overall, there were no consistent indications that the device-trained groups differed from the groups without such training.

JOHNSON, J.H. *An evaluation of a device designed to teach the principles of trimming an aircraft*. Naval Aviation Medical Centre, Pensacola, Florida, U.S.A. Special Report No. 61-1, 1961.

During their first week of primary training, an experimental group of students were given special training using a device designed to teach the principles of trimming an aircraft. They were compared with a matched control group who received no special training. In subsequent simulated manoeuvres, no significant differences in performance were found between the groups for any manoeuvre. However, more of the differences that did occur were favourable to the experimental group. This was especially true of students with high aptitude. There was much more variability of performance later on in the training programme among the experimental group. It may be, therefore, that the training device makes possible quicker recognition of the potential of the students.

JOLLEY, O.B. and CARO, P.W. *A determination of selected costs of flight and synthetic flight training*. HumRRO TR-70-6, 1970.

This paper is concerned with cost-effectiveness. The authors found that, during 1967, replacement of one hour of flight training with about 6 hours of training in the simulator would result in an overall reduction in both the cost of training and the density of air traffic at the Aviation School.

KELLEY, C.R., BOWEN, H.M., ELY, J.H. and ANDREASSI, J.L. *Tracking training III: Transfer of training*. NTDC 1908-00-3, January 1960.

The authors studied transfer of training in tracking tasks, paying particular attention to the existence and nature of a general tracking skill. Data was collected from field studies, pilot studies and laboratory experiments. Field studies indicate that there is a general carry-over of training from one aircraft to another which, however, does not extend to the details of control skill. Present trainers can teach procedural and instrument skills but they fail to teach particular control skills. Pilot studies indicate that transfer between different vehicular systems is high when instruments and controls are similar. Very stable high-order tracking systems seem to the operator to respond like lower-order systems. Stability seems to be the most important single variable in developing tracking skills. In transferring from one- to two-dimensional control there is a high positive transfer with a stable system and some

positive transfer with an unstable system. The use of a predictor display is highly effective for principles training. Laboratory experiments indicated that six tracking training conditions varying in stability and number of control dimensions were all effective in tracking training. The most effective condition employed variable stability while the poorest condition was the criterion system, which was the most unstable. General tracking training produces significant increases in skill in the control of systems having widely different dynamic characteristics.

KINGDON, R.L. *Concept of operations for a full mission fighter simulator (FMFS)*. AD-785901, 1974.

The author sets out the operational potential of a FMFS, providing visual and radar simulation for supplemental training in air-to-air, air-to-ground, formation/refuelling and ECM/ECCM mission exercises.

KNOOP, P.A. *Advanced instructional provisions and automated performance measurement*. Human Factors, 1973, 15, 583-597.

A simulation system is being developed to support experiments oriented toward quantifying the effect on transfer of training of alternative training and simulation techniques. Included in the system is sophisticated training research software which automates most of the functions traditionally performed by simulator instructors and operators. Also under development are techniques for automatically assessing pilot proficiency in the simulator and in the operational aircraft. Recent feasibility studies in performance measurement resulted in identification of necessary flight variables for assessing proficiency on two Undergraduate Pilot Training manoeuvres (lazy 8 and barrel roll), established alternative approaches to developing measurement techniques on a broader scale, applied existing technology to develop an inflight data acquisition system for the T-37 (two turbojet engines) aircraft, and raised issues regarding standardisation in instruction and rating procedures.

LANIER, H.M. and BUTLER, E.D. *An experimental assessment of a ground trainer in general aviation*. FAA ADS-64, 1966.

The authors assessed the teaching effectiveness of a pilot trainer used to develop primary and IF proficiency. The design of this study required the selection of three groups of candidates, differential use of the trainer with each of these three groups, and comparison of the measures of training progress and attained proficiency versus a comparison group of candidates taught without the use of a trainer. The experiment required the selection of ten pilots, all with minimum IFR experience, to be trained to the standards of flight performance required for instrument rating, using the trainer combined with flight instruction. Trainer instructional hours and aircraft instructional hours required to develop proficiency in primary flight ability and IR ability are reported. The results revealed that the trainer does not reduce the total number of instructional hours necessary to achieve flight proficiencies, but the trainer does reduce the number of aircraft instructional hours required to acquire such proficiency. The trainer was found to be of most value in developing navigational competence and command ability.

LOWES, A.L., ELLIS, N.C., NORMAN, D.A. and MATHENY, W.G. *Improving piloting skills in turbulent air using a self-adaptive technique for a digital Operational Flight Trainer (OFT)*. NTDC 67-C-0034-2, August 1968.

The aim was to determine the feasibility of supplying adaptive principles to flight simulator training functions using an OFT. Eighteen non-jet pilots were assigned to two groups and were given a constant amount of simulator practice at maintaining a constant altitude during simulated air turbulence. One group was trained using an adaptive technique and the other was trained by conventional methods. It was hypothesised that adaptively trained pilots would be more proficient when transferred to a simulation of an aircraft flying in clear air turbulence than would the conventionally trained pilots. Resulting data supported this hypothesis.

#### *Conclusion*

Self-adaptive principles are feasible in the performance of simulator training functions.

MAHLER, W.R. and BENNETT, G.K. *Special devices in primary flight training: Their training and selection value*. SDC 151-1-18, 1949.

Part I of this report presents the results of an experimental study to evaluate flight trainers used for primary training. The results indicated that the types of trainers studied tend to reduce the number of accidents and failures in subsequent flight, and to reduce the amount of flight time required for proficiency by about a half-hour per student. However, the authors feel that the results do not justify either abandonment or full-scale incorporation of such training into the regular syllabus. Part II of this study presents data concerning the value of the Orientation Test, as used in three trainers, for predicting subsequent flight performance.

MAHLER, W.R. and BENNETT, G.K. *Psychological studies of advanced naval air training: Evaluation of Operational Flight Trainers (OFTs)*. SDC 999-1-1, 1950a.

This report presents the results of an evaluation of OFTs with regard to training-time saving, quality potential (improving efficiency), and trainer design improvement. It was found that flight time cannot be saved in the familiarisation phase by use of OFTs but during the instrument, basic and advanced stages some savings can be made.

OFT training does make a difference in the proficiency of students, with fewer serious errors and fewer total errors on most manoeuvres. As to trainer design, "air work" tasks were not simulated as closely as procedural tasks and a suggestion is made that the specific purpose of the trainer be defined. Further recommended for study is the potential value of trainers for operational and reserve flight training.

MAHLER, W.R. and BENNETT, G.K. *Psychological studies of advanced naval air training. Analysis of flight performance ratings.* SDC 999-1-2, 1950b.

The objective was to relate measures of flight proficiency in basic training to those in advanced training. Eleven classes of naval student pilots (numbering 369, 250 of whom completed advanced training) were studied and a positive but small relationship was found. It is suggested that performance measures largely based on subjective grades are not of sufficient reliability. Recommendations are made for improving the assessment of performance, including the development of an objective-type check-flight rating system.

MATHENY, W.G. *Training simulator characteristics: Research problems, methods and performance measurements.* Proceedings of a conference convened at US Army Aviation Centre, Fort Rucker, Alabama, U.S.A., November 1973, 137-148.

Most of this paper is devoted to a proposed method for reducing the time and cost of evaluating the effectiveness of simulator designs or training procedures. The author proposed the use of the concept of "perceptual equivalence" in training research as a substitute for the classical transfer for training model. The method involves precisely defining and measuring the input and output of the operator and the system. By configuring a simulator to be "perceptually equivalent" in input and output to the criterion aircraft, positive transfer would be assured and the simulator itself could serve as a criterion device for further training research.

MATHENY, W.G., WILLIAMS, A.C., DOUGHERTY, D. and HASLER, S.G. *The effect of varying control forces in the P-1 trainer upon transfer of training to the T-6 aircraft.* HumRRO Report 53-31, 1953. CONTROL and DISPLAY.

McCULLOCH, G. *How United trains DC-10 pilots.* Shell Aviation News, 1972, 408, 2-6.

This is a review of the training given to United Air Lines (Chicago) DC-10 pilots on a simulator which embodies all the modern features of the B-747 simulator plus "instant replay". This allows the instructor to review immediately the student's flying techniques. The course is based on "phase of flight" rather than on a systems approach. This Flight Guidance System is taught in a series of "building blocks" spread over the whole 28 days of training. The syllabus is described in day-to-day detail. An hour in the simulator costs one-tenth as much as an hour in the DC-10. The visual system has a day/night/dusk capability and unlimited changes in visibility and ceiling height.

MELTON, C.E., MCKENZIE, J.M., KELLN, J.R., HOFFMAN, M. and SALDIVAR, J.T. *Effect of a general aviation trainer on the stress of flight training.* Aviation, Space & Environmental Medicine, 1975, 46, 1-5.

Sixteen students were given flight training in a standardised 35 hour syllabus. Eight of the subjects (experimental group) received 10 hours of their training in a Link GAT-1 trainer and 25 hours in a Cherokee 140B (single piston-engine) plane. The other eight students (control group) received all their training in the plane. The resting heart-rate, physical work (as measured by oxygen consumption) and urine chemistry were measured. Objective flight tests given four times during the syllabus indicated no significant differences between the experimental and the control group. Furthermore, a check pilot who did not know to which group a student belonged could not differentiate between the groups. It was concluded that 10 hours of training in the GAT-1 did not compromise flying skill, as judged by the check pilot.

MENGELKOCH, R.F., ADAMS, J.A. and GAINER, C.A. *The forgetting of instrument flying skills.* Human Factors, 1971, 13, 397-405.

A study of forgetting was conducted using a simulator as the research device. Two groups of subjects were used, with one group getting twice as much original training as the other. The retention interval was four months for both groups. The principal result was that discrete procedural response sequences had statistically and practically significant loss over the retention interval but proficiency in controlling flight parameters (tracking), and statistically significant losses in only some instances and never in operationally significant amounts.

MESHIER, C.W. *Air combat manoeuvring training in a simulator.* Proceedings of AGARD FMP/CCP Symposium 'Flight Simulation/Guidance Systems Simulation', The Hague, Netherlands, October 1975.

The Tactical Air Command Aerial Combat Simulation is an attempt to mesh simulator and flight training, using a fixed-base visual fighter simulator to improve combat skills. The trainer configuration was developed from a review of US Industry and NASA facilities. Instructional facilities were added to permit comprehensive monitoring of simulated combat with appropriate controls. In addition, a system of automated grading is provided, summarising each student's performance through the use of a computer printout and finally, to teach the course, a training syllabus was developed for the simulator. Cockpits are configured to the F-4E (Phantom) aircraft and feature the lead computing optical sight system and the armament system controls. An instructor seat is juxtaposed as a jump seat alongside one cockpit and equipped with problem controls and a three-dimensional isometric display of the engagement. The display is videotape recorded for examination. Each pilot is graded on his ability in air combat manoeuvring, and training is adapted accordingly.

MEYER, D.E., FLEXMAN, R.E., van GUNDY, E.A., KILLIAN, D.C. and LANAHAN, C.J. *A study of simulator capabilities in an operational training programme*. AMRL TR-67-14, May 1967.

This experiment was conducted to find the effects of simulator training to criterion proficiency upon time required in the aircraft. Data was also collected on proficiency levels attained, self-confidence levels, individual estimates of capability and sources from which that capability was derived. Subjects for the experiments were 48 airline captains transitioning in the DC-8 aircraft. The subjects were equally assigned to experimental and control treatment groups. Subjects in the experimental group were trained in the DC-8 simulator for as much time as required to satisfy their instructors that they could perform the required manoeuvres in the simulator at the same level of proficiency required to pass the final qualifications in the aircraft. The control group was trained using the standard curricula which required a fixed time in the simulator.

#### Conclusions

1. Questionnaire answers indicate that:
  - (a) simulators can be used to reduce further the requirements for training time in aircraft.
  - (b) simulators can be used to evaluate performance that is indicative of performance in the aircraft.
2. The feasibility of an improved approach to flight training has been suggested by the high relationship between the student's self-evaluation of his own needs in training, and his actual requirement in the simulator and aircraft.
3. Data provided by this study can be used to enhance further the effectiveness of training in simulators through design improvement in specific areas.
4. The feasibility of conducting operationally oriented research under the direction of diverse organisations with a common interest in flying training has been demonstrated by this study.

MILLER, R.B. *Task and part-task trainers and training*. WADC TR-60-469, 1960.

Procedures for dividing total performance requirements into training segments lending themselves to distinctive types of trainers are described. The principal components in the division are phase of learning and time-sharing of activities. Risks of improper part-task training are given and principles for reducing such risks are proposed. Classes of trainers identified are

- I familiarisation trainers.
- II instructed-response trainers, and
- III automatised skill trainers.

Essential training and human engineering variables are described for each class. The potentialities of Class II devices are emphasised.

MORAN, W.P. *The use of simulation to promote safety and economy in flying training*. IATA DOC/GEN 2306, 1971a.

The writer outlines how the combination of simulation and improved training techniques ensures a safe and economical flying training programme. In a five year period, American Airlines has reduced training in flight and flight check hours by more than 75 per cent. There are strong indications that a goal of total simulation for all training and flight checks will become a reality. Using several commercial jet aircraft as examples (among them the B707, B727 and B747), the author compares current times and costs of training crewmen in the aircraft and in the simulator.

#### Conclusions

1. The simulator and visual system must sufficiently duplicate the aircraft flight characteristics and environment for the training to be effective.
2. The training technique must be adequately refined to optimise the use of available equipment.

MORAN, W.P. *Simulation - the only safe way*. 24th Flight Safety Foundation Annual International Air Safety Seminar, Mexico City, Mexico, October 1971b.

The author reviews the contributions made to aircraft safety by recent innovations in training methods and equipment. The use of modern digital computer simulators with visual and motion systems is discussed and the B-747 training programme is described. The improved fidelity of simulator and visual systems is pointed out, evidence of learning transfer from the simulator to the aircraft is presented and training on the simulator for emergency procedures is discussed. The simulator is now believed to be an appropriate device for total training.

MUCKLER, F.A., NYGAARD, J.E., O'KELLY, L.I. and WILLIAMS, A.C. *Psychological variables in the design of flight simulators for training*. WADC TR-56-369, January 1959.

In the design, construction and use of simulators and trainers there are two general problem areas. The first of these is the degree of fidelity of physical simulation that can be achieved between the trainer and the aircraft. This is the concern of the design engineers. The second problem area concerns the training value that results from the use of the device. This is a psychological problem of transfer of training from the device to the aircraft that involves the psychological similarity between trainer and aircraft tasks, i.e. psychological simulation. A survey of many of the problems that have arisen in the context of psychological simulation is included. The existing training research literature on trainers and simulators is evaluated and a number of experimental programmes are suggested.

NEWELL, F.D. *Criteria for acceptable representation of airplane dynamic responses in simulators used for pilot training.* NTDC 1146-1, October 1962.

This report deals with the application of measured pilot sensitivities to airplane dynamic response characteristics and to acceptance criteria for the Aviation Weapon System Trainer. Reasons why simulators should be subjected to transient response tests, the origin and applicability of handling-qualities evaluation data, and the evaluation pilot are discussed. A specific discussion of each important longitudinal and lateral-directional handling qualities parameter is given. Pilot sensitivity to each parameter is determined. On the basis of pilot sensitivities determined from this study, accuracy requirements for simulators are given and discussed. A fundamental premise of the study is that the simulator reproduces the dynamics of the aircraft well enough so that the pilot in training will use the same techniques in the simulator as he will in the aircraft.

ONTIVEROS, R.J. *Capabilities necessary, characteristics and effectiveness of pilot ground trainers. Phase II. Visual reference flight manoeuvres.* FAA NA-73-15, 1973.

The idea was to establish guidelines for the development of standards to determine the acceptability of trainers used as primary training devices in lieu of instruction in the aircraft. Ten non-pilots were trained to proficiency in pre-solo flight manoeuvres on a fixed-base trainer which had a simple visual display responding to pitch, roll and yaw motion. Their capability was then evaluated by a flight check in a Cherokee 180 (single piston-engine).

#### Results

A positive and effective transfer of training for performing a majority of VFR pre-solo manoeuvres can be achieved with the trainer. Attributes of the trainer which contributed to positive transfer are defined. Manoeuvre situations which resulted in zero training transfer during aircraft validation flights are detailed. The characteristics deemed necessary for trainers to be effective for primary training are defined.

ONTIVEROS, R.J. *Effectiveness of a pilot ground trainer as a part-task IFR flight-checking device. Stage 1. Interim Report Apr–Sept 1974.* FAA NA-74-51, 1975.

This is the first stage of a two-stage experiment to find the effectiveness of using a simulator for training non-instrument-rated pilots in instrument approaches and related instrument flight procedures. Ten private pilots were trained to perform VOR, ADF and ILS approaches in a simulator which represented a single-engine general aviation aircraft. The subjects' ability, achieved through trainer instruction, was evaluated by a flight check in a Cessna 172. The results indicate positive transfer.

ORNSTEIN, G.N., NICHOLS, I.A. and FLEXMAN, R.E. *Evaluation of a contact flight simulator when used in an A.F. primary flight training programme: Part II. Effectiveness of training on component skills.* AFPTRC TR-54-110, 1954.

The authors present an analysis of the effectiveness of the P-I simulator in teaching certain components of contact and IF skills. Specific manoeuvres are investigated and the contribution of simulator training to each is ascertained. The results support and expand the implications of the first study in this series. Both indicate that training with the P-I simulator is effective. This second study indicates, however, differential effectiveness of simulator training for various manoeuvres and components of flight performance. Simulator training appears to be most effective with respect to manoeuvres the performance of which does not exceed the design limitations of the trainer and manoeuvres which are heavily weighted with procedural components.

PAYNE, T.A., DOUGHERTY, D.J., HASLER, S.G., SKEEN, J.R., BROWN, E.L. and WILLIAMS, A.C. *Improving landing performance using a contact landing trainer.* SDC 71-16-11, 1954. VISUAL CUES.

POMAROLLI, R.S. *The effectiveness of the Naval Air Basic Instrument Trainer (NAVbit).* Naval Aerospace Medical Institute, Pensacola, Florida, U.S.A. Special Report 65-7, 1965.

#### Purpose

To evaluate the effectiveness of NAVbit and to find out whether presenting the Link hop syllabus in a single block prior to actual flight would be preferable to presentation in an alternating fashion.

#### Equipment

The NAVbit Device, I-CA-1, is designed to provide instruction and practice in all phases of instrument flight, radio range procedures and radio navigation techniques. It is modelled on the T-28 plane.

#### Subjects

Five flight students took part. They were from Basic Training Command and had just completed the transition-precision-aerobatic stage in the T-28 aircraft. They were briefed as to the nature of this study.

#### Method

Each student did 18 hops in the trainer, ten during the Basic Instrument stage. Simulator runs were interspersed with training flights in the T-28. During training each student was asked to keep a diary, an hourly log, and to complete questionnaire forms. Individual student reaction to the NAVbit was examined.

### Conclusions

Based on a formal study conducted by the Psychological Corporation and backed by the present study which deals with student perception of, and attitude towards, the trainer the author concluded that:

1. The NAVbit is doing an effective job as an aid to teaching instrument flight.
2. The expense of providing a more elaborate simulator would not be justified in terms of increased effectiveness.
3. The students themselves feel that this trainer is adequately fulfilling its purpose of teaching procedures, scan and the reading of instruments.

### Recommendations

- (a) Retain the NAVbit in the instrument phase of flight training.
- (b) Present the Link hop syllabus in a single block prior to actual flight rather than in an alternating fashion.

POVENMIRE, H.K. and ROSCOE, S.N. *An evaluation of ground-based trainers in routine primary flight training.* Human Factors, 1971, 13, 109-116.

### Purpose

The relative benefits of two types of flight training equipment were evaluated in a routine instructional situation with no particular constraints placed on the instructor as to how he used the equipment, and without interfering with the normal course of training. The specific objectives were:

1. To evaluate the flight instructors' ability to predict success in private pilot training on the students' initial performances in each of two ground trainers.
2. To find the relative value of 11 hours of instruction in two different ground trainers when substituted for 11 hours in the aircraft, and
3. To develop an objective scale for checking flight proficiency.

### Subjects

48 members of a University aviation class served as subjects. They were divided into four equal groups (A, B, C and D).

### Method

GROUP A consisted of a non-experimental category composed of students with previous flying experience. They took part only in the flight checks.

GROUP B were trained only in the aircraft. They were given 46 hours of instruction.

GROUP C received 35 hours of aircraft time and 11 hours of instruction in the Link AN-T-18 trainer.

GROUP D had 35 hours of aircraft time and 11 hours in the GAT-1 trainer. Performance measurements were made at specific intervals on manoeuvres required for pilot certification. Average performance scores for each group for each manoeuvre were calculated. Inter-group comparisons were made at corresponding flight points.

### Conclusions

1. Ground-based trainers as represented by the new GAT-1 and the old AN-T-18 can yield high transfer of learning to students whose instructors are given a free hand in a routine training programme.
2. General application of GAT-1 trainer time toward the flight experience requirement for private pilot certification appears warranted on a one-for-one basis up to some limit equal to or greater than 11 hours.
3. To establish the optimum amount of ground trainer use in the private pilot curriculum, the Transfer Effectiveness Function should be found experimentally for each trainer on a basis of certification.
4. The prediction of pilot aptitude based on a student's performance during his first two hours in a ground trainer appears promising. It also appears possible that instructors can learn to use a common objective rating scale so that a given performance would be scored the same by many observers, independent of the student's flight experience level. The reliability with which instructors and check pilots can do this should be established through more flight experimentation.

POVENMIRE, H.K. and ROSCOE, S.N. *Incremental transfer effectiveness of a ground-based general aviation trainer.* Human Factors, 1973, 15, 534-542.

The authors conducted an experiment to find the incremental transfer effectiveness of a representative ground-based general aviation trainer to serve as a basis for the evaluation of its incremental cost effectiveness. Four groups of student pilots were given respectively, 0, 3, 7 and 11 hours of instruction in the Link GAT-1 concurrently with flight instruction in the Piper Cherokee airplane. Average flight times for the four groups to reach the private pilot criterion reflected the postulated negatively decelerated nature of the incremental transfer effectiveness function.

PROPHET, W.W. and BOYD, H.A. *Device-task fidelity and transfer of training: Aircraft cockpit procedures training.* HumRRO TR-70-10, 1970.

This study was undertaken (a) to evaluate the use of a 2-C-9 cockpit procedures trainer for teaching ground cockpit procedures for the Mohawk aircraft (OV-1, twin-engine, turbo-prop, Army reconnaissance plane) and (b) as part of a broader study of the relationship between trainer fidelity and training effectiveness. For the latter, the performance of cockpit procedures in the Mohawk by a group of students trained in the sophisticated 2-C-9 device was compared with that of another group who received cockpit procedures training in a simple mock-up. The performance of both groups was then compared with that of a control group of students who received all of their procedures training in the aircraft. Results indicated that both training devices produced significant transfer of training, in terms of error and time reduction, to performance in the aircraft. There were no significant differences in training effectiveness between the two devices in spite of their great difference in physical fidelity and cost. Implications for the design of procedures training devices and associated training programmes are discussed.

PROPHET, W.W., CARO, P.W. and HALL, E.R. *Some current issues in the design of flight training devices*. HumRRO PP-5-72, 1972.

The author develops the argument that training equipment should be selected or designed to furnish the student pilot with the expertise required for safety and success in flight. Several considerations relating to training equipment design from the systems engineering standpoint are examined. Suggested design features based on particular student learning needs and on student learning characteristics are presented. Training equipment design features for particular categories of training objectives and for levels of training (e.g. initial training versus transition training) are considered. Also discussed is the criticality of the synthetic training programme with respect to the total training engineering process.

REID, G.B. *Training transfer of a formation flight trainer*. Human Factors, 1975, 17, 470-476.

This research was conducted to determine transfer of training from a formation simulator to aircraft formation flying. Evidence in support of positive transfer was obtained by comparing students trained in the simulator with untrained students, and with students trained in the aircraft. The experimental design provided data for a direct comparison of five simulator sorties with two aircraft sorties in an effort to establish a training cost/transfer comparison. The results indicate that the simulator training given has, at least, the effectiveness of two aircraft sorties.

RENEMANN, H.H. *Crew training in a flight simulator in case of pilot incapacitation*. DGLR Anthropotechnicians Committee, 16th Meeting, Frankfurt, Germany, November 1974. (In German).

Simulator trials were carried out to test the effectiveness of some training for aircrew, faced with the problem of pilot incapacitation in flight. Measures for improving flight safety in these circumstances are discussed.

RITCHIE, M.L. and HANES, L.F. *An experimental analysis of transfer effects between contact and instrument flight*. AD-816-553, June 1964.

Thirty-nine students learned to fly straight and level and to make level turns on instruments and on contact flight in a study designed to measure the effect of instrument experience in the airplane and in a Link Trainer on the subsequent learning of contact and instrument flight in an aeroplane. Instrument flight was shown to be harder to learn than contact flight. On instruments, straight and level was the most difficult task to learn and heading was the limit most often exceeded. On contact flight, turns were the most difficult task and no one limit accounted for the majority of errors. Learning to manoeuvre the Link Trainer reduced the time to learn, subsequently, to fly the manoeuvres in both contact and instruments, but the difference was not statistically significant. A greater reduction was obtained with instruments learned in the airplane before learning contact and relearning instruments. Relevance of the findings to other studies are discussed and recommendations for further study are made.

ROSCOE, S.N. *Incremental transfer and cost-effectiveness of flight training simulators*. ARL 74-8/AFOSR 74-5, 1974.

The cost-effectiveness of training simulators is discussed as it relates to procedural fidelity and training objectives. The law of diminishing returns on simulator transfer-effectiveness is discussed -- if a simulator costs almost as much as its counterpart plane, then when an hour of simulator time saves less than an hour of aircraft training time, the simulator will cease to be cost-effective. Moreover, recent studies have shown that fixed-base simulators are more transfer-effective than are moving-base ones. Procedural fidelity, involving easily forgotten cognitive skills, is deemed more important than perceptual-motor fidelity and more difficult to achieve. The author also discusses the selection of training devices to suit particular tasks. He illustrates points by referring to the trainers 1-CA-1, 1-CA-2, 2-B-24, GAT-1, GAT-2, and the corresponding aircraft.

RUBEN, H.D. *Pilot performance monitoring and recording in flight simulators*. Proceedings of R.Ae.S. Symposium 'Flight Training Simulators for the 70s', London, England, October 1970.

The speaker described ways in which recording equipment installed in simulators could be used to give pilots a fuller picture of how they were performing and how, with practice and guidance, they could improve their performance. Using aircraft recordings, he demonstrated the presence of pitch oscillation, during take off and flap contraction, due to the difficulty of keeping airspeed within the necessary fine limits during this phase of flight. He outlined a method of using selected data to analyse the stall situation. Recordings could also give the pilot an immediate indication of his vertical TD velocity. To the simulator ILS, he suggested the addition of a series of "gates" of gradually diminishing area as TD is approached. Passage outside a "gate" would indicate the extent of pilot error. As to mathematical problems, simulator computers could be used for the quick calculation of such entities as integral modulus of displacement and of lift coefficient.

RUNYON, R., GORDON, N.B. and CHAJET, G. *Relative motion training (a preliminary analysis)*. NTDC 20-RM-1-1M, September 1958.

This report examines the performance of a variety of perceptual motor skills in relative motion situations, and evaluates the potential of appropriate training systems. The various types of motion situations studied are those in which vehicles are involved in (1) independent motion (2) collision courses (3) pursuit courses and (4) fixed positional relationships. The kind of problems presented to the operator are clarified. Hypotheses concerning the

types of skills and/or knowledge involved in responding appropriately are formulated. Cues used in the "inside-out" (apparent) orientations are differentiated from those used in the "outside-in" (real) orientations. Some of the mathematical relationships are expressed, and some training problems likely to be encountered are discussed.

SAE Committee AGE-3, Training Equipment, Programs and Simulation. *The measurement of trainee performance in simulators and part-task trainers*. SAE 735103 (AIR-1054-A), 1972.

The authors seek to acquaint the non-technical reader with the potentialities and limitations of measuring trainee performance in synthetic training devices and to outline the steps needed to achieve these measures. They deal with the subject under the headings (1) Importance and purposes of measurement, (2) Classification of performance variables, (3) Methods of data handling and display, (4) Establishing performance criteria, (5) Validation, (6) Cost, (7) Adaptive performance measurement and (8) Problems and limitations.

SISKEL, M. and SMITH, W.D. *A preliminary training study of the H-34 cockpit procedures trainer*. U.S. Army Aviation Human Research Unit, Fort Rucker, Alabama, U.S.A. Research Memo No.6, October 1960.

This study concerns normal pre-flight and post-flight cockpit procedures for the H-34 helicopter. Two separate programmes of instruction were established for use with the H-34 Cockpit Procedures Trainer. A third programme of instruction was given exclusively in the helicopter as a part of the regularly scheduled transition training.

#### *Conclusion*

A substantial increase in the efficiency of learning cockpit procedures for the H-34 helicopter can be effected by giving three-hour pre-flight training in the H-34 Cockpit Procedures Trainer.

STANEK, P. *Study of capabilities, necessary characteristics and effectiveness of pilot ground trainers*. Vol. I. FAA RD-72-127, 1, 1973.

The author tested the capabilities, necessary characteristics and effectiveness of trainers in developing primary flying skills, those manoeuvres and procedures defined in FAR 61.37, 61.87, 61.117 and appropriate Flight Test Guides limited to single engine planes. During the first phase of the experiment, 30 subjects were trained to proficiency under part 61.87, 15 in aircraft only and 15 in combined trainer and aircraft. During the next phase, 20 of the original 30 were trained to proficiency under 61.37 and 61.117, 10 in each group. A third phase of the experiment tested additional subjects in various procedures with varying levels of simulator capability. The results show that manoeuvres and procedures may be taught effectively and efficiently in a trainer. Volume II contains the Addendum, Summary of Flight Instructors' Views.

SULZER, R.L. *A system of low-cost visual collision avoidance training*. National Aviation Facilities Experimental Centre, FAA, Atlantic City, New Jersey, U.S.A. 1971.

#### *Purpose*

To find the effectiveness of a system of low-cost aids designed to provide practice in time-sharing between in-cockpit flight duties and external visual search.

#### *Subjects*

Fifteen FAA pilots took part. Their ages ranged from 30 to 54 years and their flight experience, from 15 to 1600 hours.

#### *Equipment*

The motion simulator used had the flight characteristics of a Cessna-182 (single piston engine) aircraft. The instrument panel was equipped for IFR flight with a full set of navigation and engine instruments. The radio aids permitted the pilot to practice navigation and approach procedures using dual VOR/ADF low frequency radio range and ILS. The simulator was situated at the centre of a 10-foot radius sky dome.

#### *Method*

The pilots simulated cross-country flights while images of intruder aircraft (constituting targets to be detected) on possible collision courses were projected on the dome. Target luminance and target azimuth were varied experimentally. The pilots had four practice sessions before the tests began.

#### *Findings*

At the outset, wide individual differences in detection scores, unrelated to the total logged flight time, were found. Time-sharing practice in a trainer, with a simple and low-cost target projector added, was effective in improving intruder detection. Most of this improvement occurred during the first four practice sessions and was achieved without any deterioration in control, performance or detection of instrument warnings. Since very experienced pilots were not necessarily superior in search performance, benefits may accrue from including a session using these procedures in routine pilot proficiency checks.

TERRY, R.P. *Selecting a basic flight procedure trainer*. Shell Aviation News, 1972, No.406, 8-11.

The criteria used in the selection of a trainer for the Oxford (U.K.) Air Training School are discussed together with the available models taken into consideration. It was decided to evaluate the Model 101 - G of Frasca Aviation.

Various adjustments were made to adapt the trainer to the Training School needs. The various aspects in the use of the Model 101 - G as a teaching tool are examined.

TERRY, R.P. *Towards jet indoctrination*. Shell Aviation News, 1973, No.416, 20-23.

The author describes the operation of the Jet Procedures Trainer, based on the Comet aircraft, at Oxford (U.K.) Air Training School. It is used mostly for transition training to jet aircraft. The problems of pilots transitioning from straight wing, propeller-driven aircraft to swept wing jets are examined, giving attention to aspects of pilot instruction, selection procedures for ensuring the maintenance of pilot standards and the correction of out-dated training concepts. Specific problems which can be rectified with the Jet Procedures Trainer are related to basic swept wing jet aircraft theory, crew co-operation, altimeter setting procedures and the revision of basic procedures.

THOMAS, W.L. *The use of Specific Behavioural Objectives (SBO) in simulator and curriculum development and other simulator uses*. Proceedings of Second R.Ae.S. Flight Simulation Symposium, London, England, May 1973.

The SBO concept, as part of a systems approach to flight training, has been given considerable attention within the industry. This approach to the development of new programmes and to the redevelopment of existing programmes details the objectives the training programme must achieve and serves as an effective resource for determining evaluation criteria. Progress made in adapting simulators and programmes to suit FAA requirements is discussed. Application of the SBO concept can cut down on the simulator programme by eliminating facets of training that a pilot can already accomplish proficiently. Of major importance are the effects the SBO concept might have on simulator design. Some of the difficulties most likely to be encountered in the simulator phase of training are also discussed.

VALVERDE, H.H. *A review of flight simulator transfer of training studies*. Human Factors, 1973, 15, 510-523.

The use of operational equipment is considered to be the most effective and valid means for training pilots. Often, however, it is undesirable to use real equipment for training if suitable simulators are available. For example, the use of aircraft (1) is very expensive (2) imposes limitations on the manoeuvres the student pilot can practice with safety and (3) imposes weather limitations on the learner. Thus, practical decisions as to the type of training device used depend on compromises between economic and training objectives. The author reviews training techniques and transfer of training, using literature available at the U.S. Defence Documentation Centre.

VREULS, D., OBERMAYER, R.W. and GOLDSTEIN, I. *Trainee performance measurement development using multivariate measure selection techniques*. Final Report. Dec 1972-Dec 1973. NAVTRAEQUIPCEN-73-C-0066-1, 1974.

The object was to extend a descriptive structure for measuring student performance during training to a fixed-wing high performance aircraft simulation, and to develop measure-selection statistical techniques. The approach required: (1) definition of candidate performance measures for the simulated flight task, (2) development of computer programmes to acquire raw data and produce measures for eighteen one-hour training sessions with four candidates, and (3) to develop methods to reduce these measures to a small set, reflecting the skills change that occurs as a function of training. It was desired that the resultant measurement have the capability of discriminating between different levels of proficiency and of predicting later performance, based on measures of current performance. Two measure-selection methods developed and the results of applying them are discussed.

WILCOXON, H.C., DAVY, E. and WEBSTER, J.C. *Evaluation of the SNJ Operational Flight Trainer (OFT)*. SDC 999-2-1, 1954.

The authors assessed the training value of the SNJ OFT and they compared it with the simpler, cheaper NavBIT. Both were effective aids in training. The NavBIT was equal in effectiveness to the SNJ OFT in basic instrument training and slightly superior for radio range work. It was just as good in providing cockpit familiarisation. Synthetic training should be given in a block prior to flying rather than interspersed with flight. A progress-at-own-rate flight schedule plus a rigorous block of ground training saved an average of 1.3 hours of flight time during the basic instrument phase.

WILLIAMS, A.C. and FLEXMAN, R.E. *An evaluation of the Link SNJ operational trainer as an aid in contact flight training*. SDC 71-16-5, 1949.

In order to evaluate the Link SNJ trainer as an aid in contact flight training, an experiment was performed with two groups of six college students per group. One group learned a series of manoeuvres in the trainer, then relearned in the aircraft. A control group learned the same manoeuvres directly in the aircraft.

*Conclusions*. It was found that

1. training in the SNJ operational trainer resulted in a saving of flight training time in the aircraft.
2. the saving achieved averaged 7 hours 14 minutes per student for the syllabus used.
3. the saving in training time for the entire population of such students lies somewhere within the limits of 4 hours 47 minutes and 8 hours 47 minutes.

WILLIGES, B.H., ROSCOE, S.N. and WILLIGES, R.C. *Synthetic flight training revisited*. Human Factors, 1973, 15, 543-560.

Critical issues in the development and use of synthetic flight trainers are reviewed. Degree of simulation and fidelity of simulation are discussed as key design considerations. Problems in measurement of original learning, transfer, and retention are presented. Both transfer effectiveness and cost effectiveness are described as critical factors in the evaluation of flight trainers. Recent training innovations, such as automatically adaptive training, computer-assisted instruction, cross-graphics, incremental transfer effectiveness measurement, and response surface methodology, are discussed as potential techniques for improving synthetic flight training. It is concluded that broader application of simulation is necessary to meet the new demands of pilot training, certification, and currency assurance in air transportation.

WILSON, W.B. *The effect of prolonged non-flying periods on pilot skill in performance of a simulated carrier landing task*. AD 769696, 1973.

The purpose was to find if a significant loss of basic pilot skill occurs during prolonged non-flying periods. Current one-year stagnant and two-year stagnant groups of jet-qualified US Naval pilots were tested on a computer simulation of a carrier approach and landing. Performance by currency groupings was then analysed. Test subjects were subsequently re-assigned to experience groups based on individual flying hours. Least experienced intermediate and most experienced group performance was then compared. Significant variables and important parameters in retention of pilot skills are discussed. In the light of the experimental results, some possible real-world implications and suggestions are made.

WOODRUFF, R.R. and SMITH, J.F. *T-4G simulator and T-4 ground training devices in USAF Undergraduate Pilot Training (UPT). Final Report Feb 1972-June 1973*. AFHRL TR-74-78, 1974.

Twenty-one students from three UPT classes were given contact training in a T-4G simulator before contact completion training in a T-37 (two turbojet engines) aircraft. Fourteen of these subjects were then given instrument training in the T-4G before instrument completion training in the aircraft. The remaining seven subjects received their instrument training in a T-4 instruments trainer, using a revised syllabus incorporating batch training and proficiency advancement. They completed their instrument training in the T-37 plane. Check pilot scores for each of the instruction phases were used to ensure that all the students were trained to a comparable standard to previous students trained using different simulators and other training techniques.

#### *Conclusions*

Use of the T-4G simulator saved an average per student of three aircraft hours in contact training and ten aircraft hours in instrument training. Results also indicate that eight aircraft hours were saved in instrument training when the special syllabus of instruction was used with the T-4 instruments trainer.

WOODRUFF, R.R., SMITH, J.F. and MORRIS, R.A. *Use of the T-4G simulator in USAF Undergraduate Pilot Training (UPT). Phase 1. Final Report*. AFHRL TR-74-61, 1974.

The T-4G simulator has a limited visual and motion capability. It was evaluated to find the extent to which its technology could be used to substitute for flight time in the T-37 (two turbojet engines) aircraft for student pilots doing a UPT course. A special syllabus maximising the capabilities of the T-4G was used. The authors describe the first assessment phase in which six UPT students were trained in the simulator in contact and instrument flying before going on to the aircraft. They completed contact training in 23.4 flying hours per student (a saving of 3.8 hours) and instrument training in 9.7 flying hours per student (a saving of 11.1 hours).

## VISUAL CUES

ADAMS, J.J. and HUFFORD, L.E. *Effects of programmed perceptual training on the learning of contact landing skills.* NTDC 297-3, April 1961.

*Object*

To evaluate the contribution of one type of programmed presentation (perceptual-verbal-pretraining) to the learning of a contact landing task. Since the perceptual aspect can be regarded as a component of the whole landing task, this study also bears upon the part-task learning controversy.

*Method*

After several hours of classroom and simulated instrument flight training, thirty naive subjects were divided into two equivalent groups — an experimental and a control group. The experimental group had open-loop training which required them to judge a series of programmed correct and incorrect presentations of landing patterns and to identify the causes of errors. The control group did not get open-loop practice. Then each of the 30 subjects were required to perform a series of landing problems in the contact analogue landing device. Several side issues concerning methodology for evaluating pilots as well as visual attachments were also raised and investigated.

*Conclusions*

The programmed visual presentation did not help in the learning of the contact landing task. This indicates the existence of a strong interaction factor between the perceptual and motor components which could not be learned with the experimenter's programmed presentation. However, the failure of one type of programmed presentation does not annul the possibility of success for a programmed presentation of greater length, different type, or different position in the learning cycle.

ARMSTRONG, B.D. and MÜSKER, G. *Training for low visibility landings.* Proceedings of R.Ae.S. Symposium 'Flight Training Simulators for the 70s', London, England, October 1970.

The speakers outlined the work being done on the part-task simulator at the Blind Landing Experimental Unit (BLEU) at Bedford. This simulator is primarily a research vehicle and so it does not have the all-round fidelity that a commercial vehicle possesses. However, care was taken to reproduce realism where it really mattered. After describing the projector system and viewing unit of the visual aid, the speakers reviewed a six-week exercise (agreed between BEA and BLEU) which took place during Feb/March 1970. The landing situation investigated was one of low decision heights, short contact times and small visual segments. All the runs were two-pilot operations in accordance with normal BEA procedures. From the performances it was evident that this type of equipment would be invaluable for training pilots/co-pilots for low visibility approaches.

*Conclusions*

1. It is important that pilots should realise the variability of fog.
2. Crew drills must be learned and meticulously obeyed.
3. The character of the lighting patterns at airports must be learned in detail.
4. Worthwhile training can be imparted in a simulator of modest dimensions provided considerable care is taken with the visual attachment. This should be realistic rather than complicated.

DeBERG, O.H., McFARLAND, B.P. and SHOWALTER, T.W. *The effect of simulator fidelity on engine failure training in the KC-135 aircraft.* Proceedings of AIAA Visual and Motion Simulation Conference, Dayton, Ohio, U.S.A., April 1976.

MOTION CUES.

BRAY, R.S. *Experience with visual simulation in landing and take-off research.* AGARDograph 99, 1964.

The author demonstrates the part a visual system plays in research into the take-off and landing phases of flight. Given a well presented visual scene of a runway during take-off, approach and landing, a research pilot can make a valid assessment of the acceptability of a new aircraft design in so far as these critical manoeuvres are concerned. It is better to compromise the capability of presenting an overall view of an airport in order to gain a precise visual impression of motion, and adequate definition during manoeuvres on, or close to, the ground. It is important that (1) research pilots have ample time to adapt to simulator techniques and (2) an opportunity is provided for the pilot to simulate a familiar aircraft so that he may judge the progress of his adaptation before he starts to evaluate new aircraft designs.

BROWN, J.L. *Visual elements in flight simulation.* Centre for Visual Science, University of Rochester, New York 14627, U.S.A. Technical Report 73-2, December 1973.

This report describes the activities of a Working Group of the Committee on Vision of the National Academy of Sciences. This report attempts a systematic review of the problems of visual simulation, together with a very comprehensive state-of-the-art review of visual simulation facilities in the U.S.A. The main body of the report is organised under the following headings (1) Techniques for the simulation of the visual world (2) Electronically-generated displays (3) Sources of visual information (4) Dimensions of the visual display (5) Motion simulation (6) Criteria for the evaluation of simulators (7) Recommendations for further research (8) Simulation research: facilities and personnel.

The appendix of the report describes visits made by the Working Group to various simulation facilities in the U.S.A., and presents a record of discussions with engineers and human factors specialists in simulation. These discussions cover simulation philosophy, training problems, motion cue simulation, as well as the primary concern of visual simulation.

CHASE, W.D. *Effect of colour on pilot performance and transfer functions using a full-spectrum, calligraphic, colour display system.* Proceedings of AIAA Visual and Motion Simulation Conference, Dayton, Ohio, U.S.A., (loose paper), April 1976.

This paper reports an experiment concerning a computer generated, calligraphic, full spectrum colour display system, invented by the author, which can display up to 500 colours at high brightness and resolution. Red and blue colours are particularly interesting, since they produce a colour stereoscopy effect whereby red lights appear nearer than blue. The experiment examines how variations in red and blue colours used for a visual display of a runway or a perspective array might influence pilot performance, transfer function and opinion in a fixed-base simulation of approach and landing.

Six pilots performed training flights, criterion flights and flights with turbulence using an aerial image display which was either dynamic or frozen. Two runway landing approach scenes were used, either red approach lights and blue taxiway lights, or reversed. Three perspective arrays were used, using red, blue or red and blue colours.

Dynamic landing approaches found no effect of colour, although frozen landing approaches found blue to be best both on performance measures and transfer functions. For dynamic and frozen perspective array scenes, crossover frequency was higher for red/blue combination display. The results are somewhat more complicated than this simple description indicates, there being order effects present.

The author believes that improvements in visual simulation can be achieved by the use of specific colours within the display scene.

GABRIEL, R.F., BURROWS, A.A. and ABBOTT, P.E. *Using a generalised contact flight simulator to improve visual time-sharing.* NTDC 1428-1, April 1965.

Thirty US Marine A-4 (single jet) pilots were given eight time-sharing sessions in a simple, generalised, visual simulator and then compared with a control group on performance in the highly specific A-4 Operational Flight Trainer equipped with a visual display. Results indicated improved ability to detect simulated mid-air collision hazards without compromising performance in other tasks. Such training is therefore recommended as an aid in reducing the mid-air collision risks.

GRAHAM, W. REED, J. and MEYER, E. *A visual detection simulator for pilot warning instrument evaluation.* AIAA 73-916, 1973.

This simulator has been designed for the specific purpose of producing reproducible visual stimuli which will provide realistic detection ranges in air-to-air encounters by pilots who are simultaneously occupied with flying a trainer. The projection system produces a field  $20^\circ$  in elevation by  $180^\circ$  in azimuth at an average brightness of 200 foot-lamberts and with an angular resolution better than 1 arcmin. The stimuli are produced by 14 pairs of 35 mm still projectors operated in the dissolve mode every 10 seconds. Comparison of detection ranges in the simulator with those recorded in actual flight are presented.

GUM, D.R. and ALBERY, W.B. *Integration of an advanced CIG visual and simulator system.* Proceedings of AIAA Visual and Motion Simulation Conference, Dayton, Ohio, U.S.A., April 1976. MOTION CUES.

LARSON, D.F. and TERRY, C. *Advanced Simulation in Undergraduate Pilot Training (ASUPT): Systems integration.* AFHRL TR-75-59-7, 1975.

Problems and solutions during integration of the CGI visual system into the ASUPT basic simulator are described. Difficulties such as spin, stall, attitude control and timing synchronisation are addressed together with the techniques used to upgrade the simulator dynamics to meet the resolution and response fidelity required for smooth, responsive visual imagery.

LUCE, L. *Vital II.* Shell Aviation News, 1973, 419, 26-29.

The author describes the Vertical Image Take-off and Landing (VITAL II) system which is operational on one 727 flight simulator. The author claims that this low-cost, low-maintenance visual system is superior to other simulators in providing a greater simulation training potential for pilots. Basic in the operation of this system is the capability of the simulator computer to transfer aircraft attitude and position data to its visual computer. The flexibility and versatility of the system are discussed.

LYBRAND, W.A., HAVRON, M.D., GARTNER, W.B., SCARR, H.A. and HACKMAN, R.C. *Simulation of extra-cockpit visual cues in contact flight transition trainers*. AFPTRC TR-58-11, 1958a.

*Purpose*

This study was designed to provide information needed to make recommendations regarding the visual cues which should be presented in prototype visual attachments. A secondary objective was to determine informational and control design characteristics of instructional facilities required for optional training use of these devices. The study focussed on transition training of experienced pilots to fighter, fighter-bomber and interceptor aircraft with emphasis on TO, pattern, approach, landing and circuit tasks.

*Method*

Information was gathered from:

- (a) An analysis of the operational tasks involved and interviews with transitioning pilots, instructor pilots and test pilots.
- (b) Consultation with experts in training, visual perception and associated engineering, and
- (c) Inspection of existing trainers and simulators with visual systems.

*Recommendations*

Recommendations are made on:

1. The "flying" capability of the simulator in terms of airspeed, altitude, distance from a reference point, and lateral freedom in flight path.
2. The visual simulation of ambient flight conditions which call for non-routine or emergency types of flying skills.
3. The visual simulation of natural and man-made objects. This is critical from a training standpoint in terms of task involved and the skill habits of experienced pilots.
4. Information displays and controls which are used by the instructor for optional training use.
5. Fidelity of simulation parameters and miscellaneous subjects such as reflective screens.
6. Critical aspects of visual simulation requiring further research.

LYBRAND, W.A., HAVRON, M.D., GARTNER, W.B., SCARR, H.A. and HACKMAN, R.C. *Simulation of extra-cockpit visual cues in contact flight transition trainers*. AFPTRC TR-58-11 Appendix 1, 1958b.

This volume consists of a comprehensive bibliography. 137 of the references have a short summary of the operational techniques used (subjects, method, apparatus, etc.) and the results obtained in each of the experiments covered.

McGRATH, J.J., OSTERHOFF, W.E., SELTZER, M.L. and BORDEN, G.J. *Geographic orientation in aircraft pilots: Methodological advancement*. Human Factors Research Inc., Goleta, California, U.S.A. Report 751-5, 1965.

This report deals with a revision in a cinematic method of simulating low altitude flight. Cockpit instruments were synchronised with a motion picture scene. The throttle control was geared to the projector motor to provide the pilot with control of the simulated speed of the aircraft. An automated response system was devised to provide more accurate performance measurements for test runs which showed that this new technique improved geographic orientation in pilots during simulated flight.

MATTHEWS, N.O. *Helicopter flight simulators*. Aircraft Engineering, Feb, 1976, 48, 17-20.

The author examines the problems of simulating helicopter handling and flight, and he relates these problems to the existing techniques used for the simulation of fixed-wing aircraft. He compares the characteristics of CCTV visual systems, CGI systems and model projection systems which use a point light source. This latter method, despite a number of optical limitations related to the difficulty of designing small sources of sufficient light intensity, is the only one that can satisfy the important field of view requirements for helicopter flight simulation. Using this method, the author defines the requirements for a lightweight helicopter training simulator.

MATTHEWS, N.O. *The relative importance of physiological and visual factors in providing realism in flight simulation*. Proceedings of R.Ae.S. Symposium 'Flight Training Simulators for the 70s', London, England, October 1970.

The speaker explained the methods of simulating physiological and visual cues and their application. Since these cues vary so widely, he suggested the development of part-task simulators where the balance of cue type could be tailored more accurately to a particular problem. The aim should be the provision of more realism in simulation without the introduction of unnecessary complication. Most present-day simulators are multipurpose and, to achieve this qualification, manufacturers have been obliged to compromise in design, e.g. visual realism suffers in an attempt to provide a wide range of visual task simulation, while six degrees of freedom have been provided when most training tasks can be accomplished with three motion modes. As to the future, the author predicted development in the presentation of visual cues of the outside world by improvements in existing types of equipment such as film and TV systems or by greater use of computer-generated displays. At present the main problems are:-

1. The narrowness of the field of view and
2. The unrealism of visual simulation in the "low level near stationary" situation.

The former is important in the two-pilot visual presentation while both are vital for V/STOL simulation. Simulator development is envisaged to provide better control feel and performance, and higher frequency motion devices are predicted. Internal cockpit realism in visual, feel and aural areas will continue to be important for years to come.

MICHLIK, M.J. *A visual landing simulator for a ground-based trainer.* AD 732 323, 1971.

Voltage signals from a Link General Aviation Trainer (GAT-1) were used to drive a visual display system simulating the changing geometry of the outline of a runway as seen by a pilot while landing. These signals represented the aircraft's attitude, range from the end of the runway, and right-left angular deviation from the extended runway centre-line. The images were presented by a mechanical shutter system and a simple overhead projector. The projected runway image was found to agree with that calculated from the geometric equations to within four per cent.

MIDDLETON, D.B., HURT, G.J., BERGERON, H.P., PATTON, J.M., DEAL, P.L. and CHAMPINE, R.A. *Motion-base simulator study of control of an externally-blown flap STOL transport aircraft after failure of an outboard engine during landing approach.* NASA TN-D-8026, 1975. AIRCRAFT HANDLING.

MILLER, J.W. and GOODSON, J.E. *A note concerning "motion sickness" in the 2-FH-2 hover trainer.* U.S. Naval School of Aviation Medicine, U.S. Naval Station, Pensacola, Florida, U.S.A. Research Project NM 17 01 11 Subtask 3 Report 1, February 1958.

The authors reviewed the development of Device 2-FH-2 and considered the problem of motion sickness experienced in this simulator. They feel that the cause may lie in one or a combination of several modes of distortion - both static and dynamic distortions in the projected scenery, errors in the perceived directional changes of motion, and dynamic errors in the perceived angular rate of motion. Suggestions are made as to how the problem might be remedied.

MILLER, G.K. and RILEY, D.R. *The effect of visual-motion time delays on pilot performance in a pursuit tracking task.* Proceedings of AIAA Visual and Motion Simulation Conference, Dayton, Ohio, U.S.A., April 1976. MOTION CUES.

MOLNAR, A.R. and LYBRAND, W.A. *Basic development accomplished on wide-angle, non-programmed visual presentation. Vol. I, Vol. II, Appendix.* NASA 404 (2 Vols.) 1959.

Volume I presents a discussion and evaluation of equipment and techniques used in "outside world" visual presentations. General descriptions of the major basic approaches are discussed. Brief descriptions of devices using these approaches, their components, and their advantages and limitations are presented. This volume also contains a summary and formulation of fundamental design criteria which should be considered in the design of visual presentation equipment for training purposes. Finally, recommendations for research and development areas are discussed. Volume II and the Appendix contain abstracts of various documents relating to visual presentations. The abstracts cover the design approach, training purposes and characteristics, descriptions of useful components, and a brief summary of the reports reviewed. An alphabetical listing of useful references and a summary of information obtained from a questionnaire are also given.

MORRIS, E. and MATTHEWS, N.O. *New visual and motion techniques in military flight simulation.* Proceedings of R.Ae.S. Symposium 'Theory and Practice in Flight Simulation', London, England, April 1976.

The authors illustrate the differences in requirements between civil and military simulator training. Some recent developments in motion and visual systems are described, and their validity and application to military training are discussed. Military training is necessarily more complex and demanding than its civil counterpart. While the civil pilot avoids excessive accelerations and violent manoeuvres close to the ground, this is the military pilot's stock in trade. Military simulators must, therefore, provide realistic accelerations in order to acclimatise the pilot, and to give him confirmatory cues to substantiate his control inputs. A greater visual capability must be provided for effective training in LAHS flight, target acquisition and attack simulation. For these, an all-round field of view is essential.

NAISH, J.M. *Simulation of visual flight with particular reference to the study of flight instruments.* RAE TN-IAP-1099, August 1959.

The author shows how the outside world may be simulated by extending the principle of an edge-viewed ground pattern, using a normal TV technique, with the addition of a simulated sky. The ground pattern is formed by projection from a transparency representing the chosen terrain, which is endowed with movements of translation and rotation such as to permit freedom of manoeuvre within the area covered. An individual TV camera mounted with two degrees of motion freedom is used to look across the ground pattern from a point of variable height and the resulting picture, which has six degrees of freedom conveniently arranged to be compatible with the outputs of a conventional simulator, is presented on a large screen in front of the simulator cockpit, thus permitting head freedom and binocular viewing. Night and day conditions may be simulated and the visibility range is variable, but vertical ground features are not included. Details of constructions are given and values are presented for the chosen field of view, scale, and viewing distance. Picture quality for the moving scene is discussed in relation to the essential characteristics which are texture, resolution, engineering accuracy, perspective geometry, contrast, depth of focus, and horizon characteristics. Tolerances or values are indicated for these parameters and the cost is given.

PALMER, E. and PETITT, J. *Visual space perception on a computer graphics night visual attachment*. Proceedings of AIAA Visual and Motion Simulation Conference, Dayton, Ohio, U.S.A., April 1976a.

This paper presents results of experiments which attempted to obtain direct measures of the fidelity of visual space perception on a computer graphics night visual flight simulator attachment. These experiments used tried and tested psychological techniques, developed to determine the nature of visual space perception in the real world. Independent groups of five pilot subjects made perceptual judgements of a night runway scene and background city seen from eye height of 5 m at 300 m from the runway threshold. Each of three groups saw a slightly different display. The display was either basic, basic viewed through a collimating lens, or basic through a collimating lens with 10 m vertical poles placed at 100 m intervals down the simulated runway. Five perceptual tasks were run in each of the three conditions. 1. Objective size judgments of adjusting the size of a triangle at 50 m until it was perceived as having the same dimensions as a standard triangle at varying distances. 2. A similar task in which actual equality of size of triangle image on the screen was desired. 3. Adjusting a rectangle so that it represented a square at varying distances. 4. Adjusting a diamond at varying distances until it appeared to lie flat on the runway. 5. Adjusting equal distances between two pairs of lines, one pair being at varying distances.

The only task to distinguish between the three viewing conditions was the angular size task 2. Previous experiments had shown that considerable overestimation (3x) was the norm in outdoor real-world judgments. The two collimation conditions produced overestimations of 2x, and the non-collimated condition only 1.25x. Hence the collimation produces more realistic display as revealed by the angular size task, which is recommended as a procedure for evaluating visual systems for simulators.

PALMER, E. and PETITT, J. *Difference thresholds for judgements of sink rate during the flare*. Proceedings of AIAA Visual and Motion Simulation Conference, Dayton, Ohio, U.S.A., April 1976b.

Previous studies have shown that sink rates in simulators are higher than in aircraft under similar conditions. The purpose of this study was to use a psychophysical technique to investigate how well pilots perceived the critical parameters of sink rate close to the ground. Difference thresholds (the smallest difference along a sensory dimension between two stimuli which allows them to be distinguished) for sink rate were measured using a night runway visual display flight simulator attachment. The experiment was run fixed-base, and involved 16 pilot subjects in a within-subjects design. Nine sink rates were produced by the combination of three height changes and three sink durations. Pairs of trials were presented to subjects. One of the pair was a designated sink rate, and one was slightly greater, produced by altering the sink duration. Subjects had to judge which sink rate was the fastest. The psychophysical technique was a single staircase, which allowed a value to be assigned to the smallest distinguishable difference in velocity between sink rates.

It was found that as sink rate increased, so the ratio of difference threshold to sink rate decreased. This is contrary to nearly all psychophysical studies of the difference threshold, where a constant ratio is normally found. It was found that as time of sink increased, so the ability to distinguish between pairs of rates of sink improved.

PARRISH, R.V., ROLLINS, J.D. and MARTIN, D.J. *Visual/motion simulation of CTOL flare and touchdown, comparing data obtained from two mode: board display systems*. Proceedings of AIAA Visual and Motion Simulation Conference, Dayton, Ohio, U.S.A., April 1976. (Loose paper).

Four NASA research pilots made 30 approaches and landings in a flight simulation of a Boeing 737-100 aircraft. The paper reports evaluations of (1) two visual display systems (2) two motion system washout filters.

A non-linear co-ordinated adaptive washout filter motion system running in five degrees of freedom (no heave) was used for evaluation of a 1965 vintage Landing Terrain Scene Generator versus an up-to-date Visual Landing Display System. Sink rate at touchdown data is reported, which revealed very little difference between the two systems. It was clear that even the modern system still had problems in simulating attitude and sink rate.

The Visual Landing Display System was utilised in the second part of the study for evaluation of linear versus non-linear motion system washout. The dependent variable was pilot opinion, and the procedures adopted were the same as above. There was no difference in opinion for the longitudinal aircraft inputs, but roll and yaw and overall aircraft feel were rated better when non-linear motion system washout was employed.

PAYNE, T.A., DOUGHERTY, D.J., HASLER, S.G., SKEEN, J.R., BROWN, E.L. and WILLIAMS, A.C. *Improving landing performance using a contact landing trainer*. SDC 71-16-11, 1954.

#### *Object*

To test the effectiveness of:

1. A contact landing display developed for the Cycloramic Link Trainer, and
2. A programme of instruction called "Principles Training" devised to meet the requirements of this trainer.

#### *Equipment*

A large translucent screen was placed in front of the Link. The screen depicted a runway and horizon as seen from the air. The shape and position of the runway was changed automatically and appropriately in response to the flight of the trainer.

#### *Method*

Twelve non-pilot students aged 18 - 25 years were equally divided to form an experimental group and a control group. Both groups were given training in the principles of approach and landing through lectures and demonstration flights. The control group went on to qualify in the aircraft whereas the experimental group qualified on "approach and land" in the trainer first and then went on to the aircraft to qualify.

### Results

The students who used the trainer first:

1. Required 61% fewer trials in the aircraft and made 74% fewer errors than the control group.
2. Showed an overall superior ability to handle the aircraft in both approach and landing.

### Conclusion

This contact trainer enables students to visualise the important aspects of the task prior to air practice. This reduces the amount of time required to learn by trial and error in the air. The incorporation of this kind of device and instruction in regular flight training is strongly recommended.

PFEIFFER, M.G., CLARK, W.C. and DANAHER, J.W. *The pilot's visual task: A study of visual display requirements.* NTDC 783-1, March 1963.

An analysis was made of the perceptual characteristics of the pilot's visual world while performing various flight tasks. These were compared with the perceptual characteristics made available by typical non-programmed visual displays attached to flight trainers. An experiment was then conducted in the F-100 simulator equipped with a 151 visual attachment to find the effects upon training.

**Conclusions** It was found that, even among experienced subjects, performance with the visual attachment present was significantly improved both with regard to (1) the detection of in-flight emergencies and (2) the maintenance of aerodynamic stability.

**Recommendations** Suggestions are made for improvements in internal visual displays to enhance the training value of simulators.

PRILLIMAN, F.W., HUFF, W.W. and HOOKS, J.T. *A manned air-to-air combat simulator.* Journal of Aircraft, 1969, 6, 353-359.

The authors discuss the development of a simulator which uses two cockpits equipped with individual instruments, controls and visual displays. The aim is to provide a means of assessing aircraft capabilities in air-to-air combat. Either pilot can manoeuvre within his aircraft's flight envelope against an opposing aircraft. All computation is done by digital computer. A collimated display for each cockpit presents the opposing aircraft, the gunsight and the earth. The images are "stroke-written" by a Schmidt CRT projector. An 80° field of view limitation is circumvented by presenting a mirror view when the opposing airplane is in a chase position, and a radar-like synthetic display when it is not within the forward or aft 80° cone. Future developments will display the opposing aircraft position on the inside of a sphere enclosing each cockpit when its position is not within the forward view.

SCHWEINFURTH, R. *Applicability of flight simulators with no visual or motion cues.* DGLR 70-070, 1970. (In German).

The author discusses the experience gained and the validity of results obtained from using training simulators with no visual or motion cues. Simulation tests on the handling qualities of the SAAB-Viggen, the T-33 and the X-15 aircraft are summarised.

SKANS, S. *The specification of requirements for flight simulation.* Proceedings of R.Ae.S. Symposium "Theory and Practice in Flight Simulation", London, April 1976. MOTION CUES.

SPOONER, A.M. *The development of visual systems for flight simulation.* Proceedings of Second R.Ae.S. Flight Simulation Symposium, London, England, May 1973.

Alternative methods of generating visual images are reviewed and methods of presenting them to the pilot are described. The three main visual simulation methods, all capable of giving a coloured display with a visual angle about 50 degrees wide, are a closed circuit television/physical model (CCTV), cine film, and a computer generated image (CGI) system. CCTV systems have been developed over the last 10 years and the latest designs are good. Visual systems using cine film are more compact and are cheaper than CCTV, but the envelope of possible flight paths is restricted. CGI systems divide into the simple night-only visual system and the very much more complex version capable of presenting a daytime scene.

STAPLES, K.J. *Motion, visual and aural cues in piloted flight simulation.* AGARD CP-79-70, 1970. MOTION CUES.

STARK, E.A. *Motion perception and terrain visual cues in air combat simulation.* Proceedings of AIAA Visual and Motion Simulation Conference, Dayton, Ohio, U.S.A., April 1976. MOTION CUES.

STARK, E.A. and WILSON, J.M. *Visual and motion simulation in flying manoeuvring.* AIAA Paper 73-934, 1973. MOTION CUES.

SULZER, R.L. and CROOK, W.G. *Evaluation of low-cost collision avoidance ground training equipment.* FAA NA-68-37, 1968.

### Object

The purpose was to find the effectiveness of a system of low-cost aids for improving visual search and in providing

practice in search techniques during simulated cross-country flight.

#### *Method*

Twelve private/commercial and three student pilots were given practice in dividing their time between in-cockpit flight duties and external search. This time-sharing practice was conducted in a GAT-1 trainer using inexpensive slide equipment to project images of intruder aircraft on possible collision courses with the trainer.

#### *Conclusions*

Results indicate marked improvement in target detection throughout the 10 sessions flown by each pilot, with no corresponding deterioration in flight control performance or detection of instrument warnings. Measurement of the development of time-sharing skills using simulated low-cost ground training equipment is recommended at an approved flight school to validate the concept.

TAIT, D.R. *The Next generation of visual systems*. Proceedings of R.Ae.S. Symposium 'Flight Training Simulators for the 70s', London, England, October 1970.

Flight simulators are modelled on the premise that training capability may be equated to fidelity of simulation.

Pilots complain that a major cause of infidelity is the visual system. To improve this the speaker suggested the following combination of small improvements rather than an expensive redevelopment programme:

1. Advances in high resolution TV camera tubes and wide band integrated circuit amplifiers.
2. Advances in high definition colour photography.
3. Improvements in computer generation of images, and
4. Improvements in lazer projection techniques applied to providing the necessary resolution brightness, contrast and colour rendition in the visual image which could be collimated at infinity to give the illusion of depth. For the betterment of simulation the writer predicts that:
  - (a) A study programme will be carried out to find the minimum visual system requirements -- based on transfer of training among a representative group of pilots.
  - (b) The next generation of visual display will provide economic improvements in picture quality.
  - (c) Researchers will pay more attention to other aspects of visual simulation now being neglected due to the present preoccupation with image quality studies and with system evaluation.
  - (d) Compromises and trade-offs will be based on experimental evidence related to training effectiveness.
  - (e) The new systems will concentrate on providing improved maintainability and reliability which will minimise operating costs.

VOGL, E. *Visual simulation for visual flight conditions*. Deutsche Gesellschaft fur Ortung und Navigation, Nationale Tagung uber Simulation im Dienste des Verkehrs, Bremen, W. Germany, Paper 3.5, April 1975. (In German).

The author describes a simulator designed to provide pilot training in combat between two fighter-type aircraft. The cockpit contains the usual instruments and controls. Ancilliary equipment has been installed to provide the pilot with realistic visual and auditory cues of dogfight conditions.

WATERS, B.K., GRUNZKE, P.M., IRISH, P.A. and FULLER, J.H.Jr. *Preliminary investigation of motion, visual and g-seat effects in the advanced simulator for undergraduate pilot training (ASUPT)*. Proceedings of AIAA Visual and Motion Simulation Conference, Dayton, Ohio, U.S.A., April 1976. MOTION CUES.

WILKERSON, L.E. and MATHENY, W.C. *Discrimination and control of pitch, roll and yaw with a grid to encode the ground plane*. BHC D-228-421-003, 1960.

#### *Method*

The performance of eighteen non-pilots in controlling pitch, roll and yaw were measured in a helicopter simulator, a projected grid pattern being used to encode the ground plane. The principal independent variable was the orientation of the grid or heading of the aircraft. The subject's task was to "fly" straight and level while maintaining a prescribed heading. Three trials were given on each orientation.

#### *Conclusions*

1. An analysis of the RMS data showed that differences in orientation of the grid plane did not affect tracking performance.
  2. An analysis of the reversal scores showed a trend toward fewer reversals with less spread when operating on the 45 degree orientation than when operating on either the 0 or 360 degree orientation.
- The implications of these findings are discussed.

WILSON, D. *Visual simulation where we are where we are going*. SAE 670303, 1967.

The author outlines the progress made in visual simulation and high definition colour systems to date. The

requirements for all-weather operation are detailed and new developments are discussed. It would seem that the immediate future is going to see the consolidation of the TV visual system with an improvement in its overall performance coupled with an appraisal by both manufacturers and operators of the training tasks that such developed systems can undertake. It would appear that emphasis will be placed on low minima operation. Advances in high quality picture production must lead to a widening of the scope of simulator training.

## MOTION CUES

ALBERY, W.B., GUM, D.R. and HUNTER, E.D. *Future trends and plans in motion and force simulation development in the Air Force*. Proceedings of AIAA Visual and Motion Simulation Conference, Dayton, Ohio, U.S.A., April 1976.

In this paper the Air Force's future trends and plans in motion and force simulation development are presented. A three-fold approach is discussed. The first approach is to determine the nature of human motion and force sensing mechanisms. The second approach, an advanced development programme involving the construction and evaluation of a g-seat device, is discussed. The third approach involves engineering development on current g-seat systems which are seen as important in the provision of sustained normal linear acceleration cues.

BARRETT, G.V., CABE, P.A., THORNTON, C.L. and KERBER, H.E. *Evaluation of a motion simulator not requiring cockpit motion*. Human Factors, 1969, 11, 239-244.

#### Equipment

One system for simulating motion cues employs a DYNASEAT made up of six differentially inflatable sections blown up by air under the control of the simulator computer.

#### Aim

To evaluate the effectiveness of the DYNASEAT in simulating motion cues.

#### Subjects

Eight active members of a flying club took part. Their flight experience ranged from 90 to 1,300 hours. Only two of the pilots had previous simulator experience.

#### Method

After some simulator practice, each subject was tested in either one of two conditions, with subjects being matched according to their flight experience. In condition 1, during the "flights"

- (a) the subject was asked to evaluate the realism of several aircraft manoeuvres with the DYNASEAT operating,
- (b) the subject rode the simul. or (seat operating) with his eyes closed and he was asked to describe the manoeuvre taking place as the experimenter operated the controls, i.e. he named the manoeuvre, rated his confidence in his judgement, but he did not rate the realism as in task (a).
- (c) the subject was asked to rate the realism of the cockpit while doing manoeuvres with the DYNASEAT in-operative.

In condition 2 the same tasks were undertaken but in the reverse order. The results were examined using analysis of variance.

#### Conclusions

Seat motion significantly increased rated realism for a series of six manoeuvres. When subjects were presented with motion cues while their eyes were closed, correct identification of manoeuvres averaged 85% and rated confidence in judgement averaged 76%. The seat was considered to be a relatively simple low-cost method for simulating motion cues.

BECK, L.J. *The effect of spurious angular accelerations on tracking in dynamic simulation*. Human Factors, 1974, 16, 423-431.

#### Equipment

The Ames Man-Carrying Rotation Device was used. This is a one degree of freedom simulator which rotates about a vertical axis. A tracking task was presented on a CRT mounted at the subject's eye level.

#### Subjects

12 commercial pilots with normal sensitivity to rotary acceleration took part.

#### Method

The author investigated the effect of spurious yaw motions on a pilot's control performance. A second objective was to compare the tracking efficiency of subjects under congruent motion, spurious motion and no motion vehicle conditions.

#### Findings

The results indicated a significant increase in the amount of error with increasing levels of spurious motion during the initially administered series of trials. The influence of spurious motion, however, was absent in a second series of trials. The data suggests that the pilots learned to compensate in their performance for the spurious inputs. It was also found that congruent visual and rotational cueing produced superior performance to that of tracking with visual information alone.

DeBERG, O.H., McFARLAND, B.P. and SHOWALTER, T.W. *The effect of simulator fidelity on engine failure training in the KC-135 aircraft*. Proceedings of AIAA Visual and Motion Simulation Conference, Dayton, Ohio, U.S.A., April 1976.

This study investigated the effect of the presence of visual and motion cues on training for recovery from outboard engine failure in the KC-135 (prototype for the B-707) aircraft, using the NASA-Ames Flight Simulator for Advanced Aircraft. Subjects were 36 USAF pilots, all qualified in the KC-135 aircraft. Phase I of the experiment involved 8 ILS approaches, flown by all subjects in the simulator with full visual and motion cues. Data from this allowed subjects to be assigned to four matched groups. Phase II involved 20 take-offs, which included 8 engine failures on the ground and 8 in the air. Simulator fidelity was varied between four independent groups. Condition

1 was fixed-base, no visuals. Condition 2 was fixed-base, with visual system operational. Condition 3 was slightly restricted motion, no visuals, and Condition 4 was restricted motion and visuals. Phase III was a test phase of 10 trials run in the simulator with full visual and motion cues. These 10 trials contained 4 ground and 4 airborne outboard engine failures. Thirty-four aircraft performance measures were taken, and multivariate statistics revealed that total roll and total yaw during the period after engine-out were the best discriminators of changes in performance during Phase III, as a result of training conditions in Phase II. For ground failures, for both roll and yaw data, presence of visual or motion alone degraded performance, but together they improved performance of roll but not yaw measures. An interaction revealed that the presence of visual cues in Phase II greatly improved recovery from the first failures encountered in Phase III. For flight failures, visual cues present during Phase II had no effect. Motion alone, and combined with visuals, improved performance for both roll and yaw data.

BERGERON, H.P. and ADAMS, J.J. *Measured transfer functions of pilots during two-axis tasks with motion.* NASA TN-D-2177, 1964.

Measurements of human transfer functions, made by matching an analogue pilot to a human pilot, have been obtained in tests where the variables were the number of axes being controlled, and operation with and without cockpit angular motion corresponding to the indicated error. The analogue pilot contained three gains which were automatically adjusted to match the pilot. The tests were made with a gimbal-mounted simulator in which the simulated dynamics represented an inertia system with linear damping, and control  $2/S (S + 1)$  where  $S$  is the Laplace transform.

#### *Findings*

The results show that, although a pilot operates in a manner similar to a linear mechanism with constant gains when in a fixed-base, single-axis control loop, the addition of a second axis to his task causes him to operate with time-varying gains. The further addition of motion to the simulation greatly reduces the amount of time variation in the measured gains of the pilot. The tests show that the measuring method promises to be a very useful means for obtaining data on human characteristics.

BERGERON, H.P., ADAMS, J.J. and HURT, G.J. *The effects of motion cues and motion scaling on one- and two-axis compensatory control tasks.* NASA TN-D-6110, 1971.

#### *Subjects*

4 NASA test pilots and 4 engineers with tracking experience.

#### *Equipment*

The tests were made in a one-man cockpit mock-up fitted with a three-axis attitude indicator. The controls were manipulated by a side-arm stick mounted on the subject's right. The motion system had certain limitations. For the single-axis task the equipment could be used in three axes (pitch, yaw and roll). For the two-axis task it could only be used for pitch and yaw or for pitch and roll. The tests with pitch and yaw were performed with the subject in a seated position, and for pitch and roll motion the subject was supine.

#### *Method and Results*

After simulator practice, each subject did a series of data runs, each lasting three minutes, to find the effects of angular motion on compensatory control tasks. They included one- and two-axis tasks with and without motion. Both full-scale motion and reduced-scale motion (tests in which the scale of motion, compared to the visual input, was reduced) were examined. The reduced-scale motion tests were performed to investigate the minimum requirements of motion inputs in those tests where motion was found to be beneficial. Little or no difference in the error measurements were observed in the single-axis motion/no motion tests. The two-axis tests (enveloping pitch and yaw or pitch and roll motion) did, however, produce a difference in the error measurements in the motion/no motion comparisons. A decrease in normalised tracking error and an increase in the closed-loop system frequency were observed when motion was added. The reduced-scale motion tests were made with the two-axis pitch and yaw task. These tests were done in a sequence starting with no motion, all the way to full-scale motion, and back to no motion. Each motion scale condition (none,  $1/16$ ,  $1/8$ ,  $1/4$ ,  $1/2$  and full) constituted a test. The normalised tracking error remained constant for full,  $1/2$  and  $1/4$  motion scaling but increased with a further reduction in motion scaling.

#### *Conclusions*

Motion may or may not be a help in controlling a compensatory control task, depending on the difficulty of the task and on the requirements of the mission. In general, angular motion is helpful if:

1. The characteristics of the plant dynamics are such that the subject can use the lead information inherent to motion to tighten the control loop, i.e. increase the system frequency without decreasing the damping ratio, or
2. Two or more variables are being controlled and the motion inputs allow the subjects to be alert to changes in the variable(s) not being closely monitored visually at the time.

BERGERON, H.P. and HOLT, J.D. *Motion-base simulator tests of low-frequency aircraft motion on the passenger ride environment.* NASA TM-X-62464, 1975.

A large amplitude motion simulator, the NASA-Langley Real-time Dynamic Simulator, was used to study passenger ride quality acceptance of low frequency aircraft motion. The motion simulated had previously been measured during routine airline flights. Passenger subjective ratings of the simulated motion were obtained and compared to ratings obtained on flights. Subjects used in the simulation consisted of both naive subjects (people who had never previously taken part in ride quality tests) and experienced subjects (people who had participated in aircraft environment tests). Each subject was tested at least twice. Three of the experienced subjects were tested up to twenty times.

### Conclusions

1. The aircraft motion which produces sickness can be realistically simulated.
2. Simulator motion can be used for evaluating low frequency aircraft motion in passenger ride quality research.
3. A small number of experienced subjects can be used to represent larger numbers of naive subjects.
4. Repeated runs with experienced subjects show no apparent run-to-run bias.

BESCO, R.O. *The effects of cockpit vertical accelerations on a simple piloted tracking task.* NA-61-47, 1961.

### Aim

This study was concerned with the effects of short term linear, vertical accelerations on tracking errors during a one-dimensional, pitch tracking task such as might be encountered during ILS final approach, formation flying, terrain-clearance flight, and the attack phase of all-weather interceptors.

### Equipment

The Pilot Operated Dynamic Flight Simulator of the Columbus Division of NAA was used. The cockpit is mounted on twelve-foot vertical rails and moves up and down the rails in response to stick movement. The aircraft simulated was the B-70.

### Method

Four engineering test pilots took part. The compensatory tracking tasks varied in frequency and amplitude of command signal excursions. Tests were made with (a) no motion (b) motion due to aircraft response only (c) motion due to both aircraft response plus mild turbulence and (d) aircraft motion plus heavy turbulence.

### Conclusions

Pilots could track significantly better with simple aircraft response motion cues. When gusts and turbulence were added to the cockpit motion, pilot performance was significantly degraded.

BORLACE, F.H. *Flight simulator motion, its enhancement and potential for flight crew training.* SAE 670304, April 1967.

This article deals with concepts of motion systems which have not been fully exploited in training flight simulators, and which promise to provide a more accurate motion system representation. An examination of the vestibular system is made and the information it gives to the pilot is shown to be of a phase advance nature. Some programming considerations of motion systems are presented. The desirability of custom designing the motion system to aid in training the pilot for specific tasks is also discussed.

BRAY, R.S. *A study of vertical motion requirements for landing simulation.* Human Factors, 1973, 15, 561-568.

The author conducted tests to find the significance of vertical acceleration cues in the simulation of the visual approach and landing manoeuvre. Landing performance measures were obtained for four pilots operating a visual landing simulation mechanised in the Ames Height Control Test Apparatus, a device that provides up to  $\pm 40$  feet of vertical motion. Test results indicate that vertical motion cues are used in the landing task, and that they are particularly important in the simulation of aircraft with marginal longitudinal-handling qualities. To assure vertical motion cues of the desired fidelity in the landing task, it appears that a simulator must have excursion capabilities of at least  $\pm 20$  feet.

BRAY, R.S., DRINKWATER, F.J. and EMMETT, B.F. *The influence of motion on the effectiveness of flight simulators in training manoeuvres.* Proceedings of NASA Aircraft Safety and Operating Problems Conference, Vol 1. 207-220, 1971.

The use of the new Flight Simulator for Advanced Aircraft has shown the value of having available lateral motion cues for the simulation of manoeuvres required in training air transport pilots. The presence of very extensive lateral motion (80 feet) has provided researchers with the opportunity to form a tentative definition of the minimum lateral motion required to produce the desired simulation fidelity. The less extensive vertical motion capability (8 feet) of the simulator provided useful cues but did not markedly reduce the problem of accurately simulating the flare and touch-down phase of landing. The overall effectiveness of the simulator in take-off and landing manoeuvres involving lateral control problems suggested that the scope of simulator training tasks can be expanded beyond those currently performed in flight and in simulators.

BROWN, J.L. *Visual elements in flight simulation.* Centre for Visual Science, University of Rochester, New York 14627, U.S.A. Technical Report 73-2, December 1973. VISUAL CUES.

BROWN, B.P., JOHNSON, H.I. and MUNGALL, R.G. *Simulator motion effects on a pilot's ability to perform a precise longitudinal flying task.* NASA TN-D-367, 1960.

### Equipment

The NASA normal acceleration and pitch simulator was used. For this test, a stationary cockpit was mounted adjacent to the movable cockpit at a height midway in the range of travel of the movable cockpit.

### Subjects

Two NASA test pilots took part.

### Method

Pilot performance was obtained for a specific task with no motion and for the same task with both pitch and vertical motion. Tests were made with a wide range of manoeuvre margin accompanied by the expected large variation of airplane short-period characteristics. The same control system with the same two widely different stick-centring spring-force gradients (0 and 240 pounds per inch) were used in both cockpits.

### Conclusions

1. The ability of the pilots to perform a close-coupled tracking task was better when performed from a moving cockpit than when performed from a fixed cockpit. The ability of the pilots to perform this task was further enhanced by the inclusion of high stick-force gradients.
2. The effect of motion was most beneficial at zero stick-force gradient. It should be pointed out that the motion cues given to the pilot were principally due to vertical motion since the pitching motion was relatively small.
3. The pilots always preferred to be supplied with motion cues. In the absence of control-feel forces, one pilot exhibited confusion as to the proper direction that the stick should be moved to retain control in conditions of poor stability. Such confusion was not evident with motion present.

BROWN, J.L., KUEHNEL, H., NICHOLSON, F.T. and FUTTERWEIT, A. *Comparison of tracking performance in the TV-2 aircraft and the ACL computer/AMAL human centrifuge simulation of this aircraft*. NADC-MA-6010/NADC-AC-6008, November 1960.

#### *Subjects*

Six people took part. These included three civilian test pilots, one US Navy pilot, and two non-pilots. All the pilots had considerable jet experience and the three test pilots were familiar with the TV-2 aircraft or its US Air Force counterpart, the T-33.

#### *Method*

After adequate training in flying the aircraft and in centrifuge runs, subjects performed a continuous tracking task

1. while flying the aircraft
2. in centrifuge runs controlled by a computer simulation of the aircraft and
3. in the stationary centrifuge gondola.

Continuous recordings of aileron and elevator control deflections were taken. Subjective opinion was obtained from a questionnaire.

#### *Conclusions*

An analysis of this preliminary experiment does not indicate any advantage in the use of the centrifuge for the study of pilot tracking performance in a manoeuvring aircraft when the maximum linear accelerations are of the order of 5 "g". Anomalous angular motions of the centrifuge caused disorientation and nausea to the subjects and probably served to offset any advantage gained by the inclusion of acceleration forces in the simulation. For the tracking tasks used in this experiment, the results of work with a fixed-base simulator provided just as good a basis for prediction of the way in which pilots would perform a specific task in the aircraft as did work performed on the centrifuge.

BUCKHOUT, R., SHERMAN, H., GOLDSMITH, C.T. and VITALE, P.A. *The effects of variations in motion fidelity during training on simulated low-altitude flight*. AMRL-TDR-63-108, 1963.

#### *Equipment*

The Grumman Multipurpose Motion Simulator was used. It has pitch, roll and heave motion and can oscillate at up to 5 cycles/sec.

#### *Subjects*

A pool of 188 male Grumman employees, between the ages of 20 and 32, took part. All were naive with respect to flying, to motion simulators, and to the motion phenomena used.

#### *Method*

Two experiments, testing the effects of variations in the fidelity of simulated motion during training on performance in a simulated LAHS mission, were performed. The first experiment served to identify some of the principal problems and led to development of a modified motion simulation programme. In the second experiment, three groups were trained on a one-dimensional (vertical) compensatory tracking task and then transferred to a criterion test (a simulated LAHS mission with turbulence).

#### *Conclusions*

1. Simulated motion during the learning of tracking skills contributes to more effective performance in criterion test situations in which motion cues play an important role (i.e. flying a LAHS mission through clear-air turbulence).
2. Performance on a procedural task (reaction time measures) during criterion testing did not differ significantly as a function of the type of training received (motion as against no motion).
3. Further research, especially that directed towards other mission environments, is needed.

CLARK, C.C. and WOODLING, C.H. *Centrifuge simulation of the X-15 research aircraft*. NADC R-9, December 1959.

These X-15 centrifuge programmes have demonstrated the potentialities of the centrifuge simulator, particularly under conditions of closed-loop pilot-computer control or centrifuge dynamic control flight simulation, for the study of pilot tolerance, restraint, instruments, controls, vehicle controllability, control techniques, and training. Although the centrifuge has only three degrees of freedom of control and hence can only partially simulate the three linear and the three angular accelerations of unconstrained flight, it has been possible to simulate the principal forces operating on the pilot and hence to "fly" an aircraft before it is built. The new technique of centrifuge flight simulation under pilot control should now join the previous techniques of mathematical design, wind tunnel testing, static control simulation, and flight in other aircraft in contributing to the development of the design of all new, and particularly of high performance, aircraft and space vehicles. A large computer is required for this type of simulation.

COHEN, E. *How much motion is really needed in flight simulators?* SAE 710488, 1971.

Although the need for motion in training simulators is accepted, there is a wide diversion of opinion on the kind and amount of motion required. The author reviews the requirements in each of the six degrees of freedom and he suggests the extent of motion desirable in each, as well as ways to exploit given motion system geometry.

*Conclusions*

Motion in at least five (all but yaw or lateral) of the six degrees of freedom is required to provide feedback fully to the pilot on his control reactions. A pitch and roll capacity similar to that of transport aircraft is desirable. Displacements in the three linear degrees of freedom need to be about 2 feet to provide a capability of two successive onset cues. Considerable research is needed to determine motion requirements in specific training situations.

DEMPSEY, T.K. and LEATHERWOOD, J.D. *Vibration simulator studies for the development of passenger ride comfort criteria.* NASA TM-X-3295, 1975.

The authors describe an experiment undertaken to find the total discomfort associated with vehicle vibration. The programme uses a three degree-of-freedom vibration simulator to determine the effects of multi-frequency and multi-axis vibration inputs on comfort. The approach to multi-frequency vibration includes a separate consideration of the discomfort associated with each frequency or band of the total spectrum, and a subsequent empirical weighting of the discomfort components of these frequency bands when in various random combinations. The results are in the form of equal discomfort curves that specify the discomfort response to increases in acceleration level for each frequency investigated. More importantly, the results provide a method for adding the discomfort associated with separate frequencies to give a total typification of the discomfort of a random spectrum of vibration.

DOUVILLIER, J.G., TURNER, H.L., McLEAN, J.D. and HEINLE, D.R. *Effects of flight simulator motion on pilot's performance of tracking tasks.* NASA TN-D-143, 1960.

The effect of simulator motion on pilot performance of a tracking task was investigated by comparing the air-to-air tracking performance of two pilots in flight, on a static simulator, and on a simulator with pitch and roll motion present. Two different attack displays were used viz., a circle-dot display and a drone display.

*Conclusions*

1. The tracking results with simulator motion present resembled the flight results much more than did those from the motionless simulator.
2. In flight, the conventional circle-dot display was superior to a drone display.
3. For simpler tracking tasks it was not possible to detect these differences.

ERDMAN, F. and DIERKE, R. *The effect of motion cues on guidance errors during simulated ILS approaches.* DGLR 70-071, 1970. (In German).

Experimental results obtained during ILS approaches with and without simulator motion are discussed.

FEDDERSON, W.E. *The role of motion information and its contribution to simulator validity.* BHC D228-429-001, 1962.

*Subjects*

Helicopter pilots and non-pilots (simulator only) took part.

*Method*

The study was designed:

1. To investigate the relative effect of motion information on performance of a simulated hovering task in both a fixed-base and a dynamic simulator,
2. To relate the above performance measures to data obtained under controlled conditions of helicopter flight, and
3. To compare performance measures using auto-correlation.

*Conclusions*

- (a) The use of motion in the simulator contributed to significant proficiency differences in both pilot and non-pilot subjects.
- (b) These differences were exemplified by the rate at which proficiency was accrued as well as by the ultimate levels of asymptotic proficiency.
- (c) Transfer from motion to a non-motion condition resulted in performance deterioration which was never regained regardless of practice.
- (d) Enhanced proficiency was related to motion cues. These served to provide "advance" information.
- (e) Control behaviour under the motion condition was exemplified by relatively higher frequency, lower amplitude control inputs.

- (f) When reduced to auto-correlation functions, the control inputs with motion approximated more closely in-flight performance than did no-motion control behaviour.
- (g) In-flight performance on the contact analogue display approximated more closely simulator performance than did contact performance in the helicopter.

FLEXMAN, R.E. *Man in motion*. The Connecting Link, 1966, 3, 12-18. Singer-Link Corporation, Binghamton, New York, U.S.A.

#### *Man in Motion*

In addition to the many sophisticated mechanical aids at their disposal, pilots use the various proprioceptive feedback cues to assist in controlling their aircraft. In time, many of their responses to these cues become reflexive, permitting correct reactions with a very small time lag. This reflexive response capacity partially explains the fineness of control and the potential for handling heavy workloads that characterise the seasoned pilot. The author discusses the reasons for including motion in simulators and he presents some thoughts on the characteristics of the motion spectrum that can, and should, be simulated, e.g. those that depict the direction and onset of accelerations, characteristic vibrations, heavy turbulence, critical buffeting cues and the correlated disturbances associated with specific malfunctions. He lists the benefits that accrue from the inclusion of a motion system as:

1. Transfer of training effects are increased.
2. The enhanced realism of trainers that provide reasonable motion cues will increase the level of acceptance of the device by both instructors and students.
3. The rate of learning of pilot skills is greater for trainers with motion systems than for those without motion.
4. Higher levels of flight skills can be attained in trainers that provide motion cues.
5. Training in the detection and response to certain in-flight emergencies will be deleterious if practised in a fixed-base simulator.
6. When simulators are used for assessing pilot proficiency, more valid predictions can be made to the flight situation if motion is provided in the simulator. Furthermore, the motion cues can be used as a forcing function to increase the discriminatory qualities of the test. Finally the repeatability of the motion cues in the test situation can increase the reliability of the test itself over and above that which can be attained in the actual flight situation.
7. If the simulator also provides realistic visual cues, inclusion of motion simulation may reduce the incidence of motion sickness.
8. If the simulator is used for research to explore maximum performance envelopes of pilots or of new training techniques, motion cues can be used as a dependent variable to extend the research and enhance the applicability of the findings.
9. When simulators are used for predetermining handling qualities of new aircraft, simulation with motion will make it possible to obtain more valid ratings from experienced test pilots.

GIBINO, D.J. *Effects of presence or absence of cockpit motion in IF trainers and flight simulators*. ASD TR-68-24, 1968a.

By reference to relevant literature, the author examines the effects on crew members of using training devices with and without a motion system. A synoptic bibliography is included.

#### *Conclusions*

1. A fixed-base cockpit should not be used to judge pilot performance or to judge the fitness of an individual to be a pilot.
2. A moving-base cockpit, even on an instrument trainer, provides a substantial improvement in training realism.
3. Sophisticated simulators should not be purchased by the USAF without motion systems of comparable sophistication.

#### *Recommendations*

The limitations of fixed-base cockpits should be considered before training programmes are structured around them. New fixed-base cockpits should be procured only after the limitations on the training programmes are fully considered.

Von GIERKE, H.E. and STEINMETZ, E. *Motion devices for linear and angular oscillation and for abrupt acceleration studies on human subjects (impact)*. National Academy of Sciences, National Research Council, Washington DC, U.S.A. Publication 903, 1961.

The authors describe the purposes, design principles, motion capabilities, and control and safety features of about forty facilities (including motion simulators) designed to study the effects of linear and angular oscillations and of abrupt acceleration on human safety and performance. Photographs or schematic drawings of the design are presented for those devices for which they are available.

GRAHAM, D.K. *A rationale for moving-base flight simulation and a preliminary statement of the motion requirements*. The Boeing Corporation, Seattle, Washington DC, U.S.A. D6-57149, 1968.

The logic supporting the need for moving-base simulation in system research and development is presented. This is based on a survey and analysis of pertinent literature. The author found that:

1. Physical motion in simulation produces a change in aircrew behaviour from that obtained with fixed-base

simulation, and

2. The behavioural change produced by motion is sufficiently significant that, were the change not produced and observed, erroneous and potentially costly and disastrous aircraft system design decisions could be made.

Physical motion is required for the simulation of:

- (a) Tasks in which motion substantially helps the pilot, e.g. carrier and other non-normal approach and landing, V/STOL low speed operations, training on primary controls and displays and pursuit tracking.
- (b) Tasks in which motion substantially hinders the pilot, e.g. flight in turbulence, emergency procedures and manoeuvres involving high acceleration forces.

Physical motion is not required for the simulation of:

- (a) Tasks requiring little or no physical motion, e.g. normal landing, lead-collision tracking in level flight.
- (b) Tasks in which motion occurs but neither aids nor hinders the pilot, e.g. heading holding during moderate acceleration forces, altitude holding in Dutch roll or yaw-damper malfunction.

Moving-base simulation is critical for the study of flight in turbulence, and in aircrew training for turbulence penetration. In the military field, heavy turbulence is generally encountered in low-altitude high-speed missions. From a safety standpoint, commercial operators are concerned about clear-air turbulence, choppy air, buffeting effects, sonic and storm penetration.

#### Conclusion

Moving-base simulation should be provided in at least four degrees of freedom — pitch, roll, heave and sway. Motion specifications for these four axes are presented.

GUERCIO, J.G. and WALL, R.L. *Congruent and spurious motion in the learning and performance of a compensatory tracking task*. Human Factors, 1972, 14, 229-236.

The authors examined the importance of congruent and spurious yaw motion in compensatory tracking by eight airline pilots. The subjects, seated in the Ames Man-Carrying Rotation Device (MCRD), tracked with  $k(s+1)$  and  $k/s(s+1)$  vehicle dynamics in fixed motion mode. Following the learning phase, five levels of spurious angular acceleration were superimposed on the motion of the MCRD. Learning of the tracking task was found to be a function of both vehicle dynamics and mode of simulation. The presence of congruent motion information reduced learning time in  $k/s(s+1)$  vehicle dynamics and resulted in lower tracking error in both vehicle dynamics. The spurious angular accelerations resulted in an increase in pilot tracking error. However, the relation between the magnitude of the acceleration and its effect was complex. The data suggests that the minimal disturbance for spurious angular accelerations during tracking is below 0.4 deg/sec.

GUM, D.R. and ALBERY, W.B. *Integration of an advanced CIG visual and simulator system*. Proceedings of AIAA Visual and Motion Simulation Conference, Dayton, Ohio, U.S.A., April 1976.

The paper is in the most part a description of the motion, g-seat and computer-generated imagery visual system of the USAF Advanced Simulator for Undergraduate Pilot Training.

One of the problems encountered in this simulator was lags present in the hardware and software of the system. Motion system and g-seat lags were of the order of 350 msec, whilst visual system and aircraft instrument lags were about 165 msec. The disparity between the visual and motion system lag was quite apparent to the simulator test pilots, although lags of the same order had not been apparent to test pilots of the Simulator for Air-to-Air Combat. In an attempt to cure the lags, the visual system was delayed until its lag equalled that of the motion system. This was not liked, and the preferred arrangement was with the visual system as fast as possible, regardless of the disparity between it and the motion system.

The problem was eventually cured by increasing the iteration rate in the computer for the motion computations.

GUNDRY, A.J. *The role of motion in flight simulator training: An alternative interpretation of some recent evidence*. IAM S-123, March 1975.

Roscoe (1974) and Hopkins (1974) have interpreted the results of the experiment by Koonce (1974) as showing that the presence or absence of motion during simulator training makes no difference to the transfer of training observed, thereby supporting the case that motion systems are not necessary in flight simulators used for training. The present report shows that Koonce's experiment does not allow this conclusion to be drawn, since there is no evidence that training occurred.

#### References

- Hopkins, C.O. *How much should you pay for that box?* Address to 18th Annual Meeting of the Human Factors Society, Huntsville, Ala., U.S.A., October 1974.
- Koonce, J.M. *Effects of ground based aircraft simulator motion conditions on prediction of pilot proficiency*. Tech. Rep. ARL-74-5/AFOSR-74-3, 1974.
- Roscoe, S.N. *Incremental transfer and cost effectiveness of flight training simulators*. ARL-74-8/AFOSR-74-5, 1974.

GUNDRY, A.J. *Man and motion cues*. Proceedings of R.Ae.S. Symposium 'Theory and Practice in Flight Simulation', London, England, April 1976a.

The author argues that the acceptable motion cue requirements for flight simulation should be determined by considering the effect of motion cues on the operator's control task.

Simulators provide disturbance and manoeuvre motion, defined as changes in the aircraft's motion arising externally and internally, respectively, to the pilot's control loop. Disturbance motion (e.g. turbulence) may be simulated at a fairly rudimentary level. Manoeuvre motion (produced by control activity) needs to be more accurately simulated when it is provided. However, manoeuvre motion needs only to be provided when an unstable vehicle is simulated.

It is suggested that the values of motion cue necessary for the simulation of particular vehicles should be determined by describing the values of that motion cue which produce control activity from the pilot which is acceptably similar to that produced in flight.

The author next discusses the characteristics of the vestibular system in relation to flight simulation. Angular motion cues should be defined in terms of angular velocity, since over the frequency bandwidth of cues provided in simulators, the dynamic response and the threshold response of the semicircular canals is determined by stimulus velocity. Thresholds are important in flight simulation to fix floor and ceiling values for onset cues and washouts respectively, but there are inherent physical and psychological differences between laboratory studies and the operational flight simulator. These differences are so profound as to make it unlikely that absolute motion thresholds can be extrapolated from one to the other. The author argues for the adoption of effective thresholds to motion in substitution for sensory thresholds, these being determined from minimum levels of motion which alter compensatory tracking output.

GUNDRY, A.J. *Thresholds to roll motion in a flight simulator*. Proceedings of AIAA Visual and Motion Simulation Conference, Dayton, Ohio, U.S.A., (loose paper), April 1976b.

This paper presents an analysis of the experimental evidence concerning the provision of motion cues in flight simulators from the point of view of the effect that they have upon the output of the operator. The author recommends a procedure for determining the minimum motion requirements of a simulator in terms of onset cue magnitude.

The author then discusses the sensory characteristics of the vestibular system, and shows that for angular motion cues within the frequency bandwidth encountered in flight simulation, the dynamic response and the threshold response of the semicircular canals is determined by stimulus velocity rather than acceleration.

The author next presents an experiment designed to determine velocity thresholds to roll motion in a small flight simulator. This sort of data is useful so that washout ceiling levels and onset cue floor levels can be determined. Roll velocity absolute thresholds were determined using a double random staircase procedure for 10 male and female non-experienced subjects. Thresholds were determined under four task conditions: (1) no task; (2) numbers in the range 0-9 presented aurally at 1.5 sec intervals, which were to be ignored; (3) numbers presented and subjects required to repeat them as they arrived; (4) numbers presented, subjects had to add three and reply. Threshold was found to increase as did the mental loading task demands, and the data fitted an attenuation model of divided attention.

The final part of the paper presents the author's reservations about using laboratory threshold data in the design of simulator motion systems, and suggests a procedure whereby relevant threshold data can be determined.

HARDY, J.D. and CLARK, C.C. *The development of dynamic flight simulation*. NADC-1 (AD 216 508), 1958.

The amount of compromise acceptable with the actual condition of flight place important restrictions on the usefulness of simulation. In a marginally stable aircraft, less compromise can be accepted and, in particular, it is desirable to have acceleration inputs to the pilot in addition to the instrument cues. This report is concerned with the incorporation of acceleration forces into the simulator.

HUDDLESTON, H.F. *Cockpit motion requirements for flight simulation*. IAM R-363, 1966.

This report consists of a review of available literature about simulator and trainer motion requirements (including some centrifuges). Part 1 deals with the terminology used for the six motion components of flight. Part 2 summarises a number of papers dealing with simulator motion cues. Part 3 sets out the motion platform specifications considered justifiable by some firms and establishments with an interest in flight training and research applications. Part 4 deals with absolute human sensory thresholds to various kinds of motion.

#### *Conclusions*

Some aspects of both the transfer of aircrew training and the applicability of research data can be influenced by the cockpit dynamics of the simulator used. Pitch and roll accelerations appear to be of prime importance, with heave accelerations a close third. The author emphasises, however, that insufficient fundamental information is available describing either how man combines various sensations into a perception of motion, or how best motion perceptions indistinguishable from those in flight can be produced by simulation. Thus it is not, at present, possible to design a motion platform from first principles to fulfil a specified crew training or human factors research requirement, although sensible approximations are being made empirically for some applications.

INCE, F., WILLIGES, R.C. and ROSCOE, S.N. *Aircraft simulator motion and the order of merit of flight attitude and steering guidance displays*. Human Factors, 1975, 17, 388-400. CONTROLS AND DISPLAYS.

JACOBS, R.S. and ROSCOE, S.N. *Simulator cockpit motion and the transfer of initial flight training*. ARL-75-18/AFOSR-75-8, 1975.

Transfer of flight training from a GAT-2 training simulator, modified to approximate a counterpart Piper Cherokee aircraft, was measured for three independent groups of flight-naive subjects. Each group of nine subjects was trained under one of three simulator cockpit motion conditions, (1) normal washout motion in bank; (2) washout banking motion in which the direction of motion relative to that of the simulated aircraft was randomly reversed 50% of the time as the cab passed through the wings-level attitude; (3) a no-motion condition. A further group of nine control subjects received aircraft training only. For the transfer groups, transfer performance measures of flight time, flight trials and errors to reach FAA performance criteria showed reliable transfer for all groups. There were no great differences between performances of the three transfer groups in the aircraft. Due to the fact that two transfer groups were trained with a motion system, and one was not, there are very different cost-effectiveness ratios for the three groups, and these are explained in detail in the paper.

JACOBS, R.S., WILLIGES, R.C. and ROSCOE, S.N. *Simulator motion as a factor in flight director display evaluation*. Human Factors, 1973, 15, 569-582. CONTROLS AND DISPLAYS.

JACOBSON, D., SCHULTZ, M.B. and BLAKE, J.C. *Effect of motion frequency spectrum on subjective comfort response*. NASA CR-138883, 1973.

For the modelling of passenger reaction to present and future aircraft environments, subjective information may be gathered on commercial flights. In addition, detailed analysis of particular aspects of reactions to the environment are best studied in a controllable experimental situation. For this, the use of in-flight and ground based simulators is suggested. It is shown that there is a reasonably high probability that there is no need for low frequency simulation, i.e. the fidelity of any simulation which omits the very low frequency content will not yield results which differ significantly from the real environment. In addition, there does not appear to be significant differences between the responses obtained in the airborne simulator environment as against those obtained on commercial flights.

JUNKER, A.M. and PRICE, D. *Comparison between a peripheral display and motion information on human tracking about the roll axis*. Proceedings of AIAA Visual and Motion Simulation Conference, Dayton, Ohio, U.S.A., April 1976.

When tracking in a moving base simulator about the roll axis a subject receives two types of proprioceptive information. One source of information is angular acceleration or velocity, sensed by the semicircular canals. Another source arises from the subject's orientation to the vertical, sensed via the vestibular otoliths and body-seat contact pressure cues. The present experiment was designed to investigate roll compensatory tracking in a simulator where by angular velocity cues could be provided to the operator without concomitant linear acceleration cues due to tilt or pressure changes. This was accomplished by using a peripheral visual display, which presented visual angular rate information in a fixed-base simulation.

Subjects were engaged in a roll compensatory tracking task using a foveal display in three conditions of (a) cockpit roll motion (b) peripheral visual angular rate display and (c) no-motion/no-peripheral display. The peripheral display consisted of horizontal bands which moved vertically at a velocity equal in magnitude and direction to the linear velocity of stationary objects located in the position of the displays during cockpit roll motion.

Root-mean-square tracking error revealed beneficial effects of both cockpit motion and peripheral display as compared to the fixed-base, no-display condition. The two former conditions were not significantly different from one another. Transfer function analysis revealed that the effect was caused by improvement in low-frequency phase lead in the cockpit motion and peripheral display conditions. This result suggests that angular rate information is of primary importance in roll tracking in a moving cockpit.

JUNKER, A.M. and REPLOGLE, C.R., *Motion effects on the human operator in a roll axis tracking task*. Aviation, Space and Environmental Medicine, 1975, 46(6), 819-822.

Three groups of four subjects engaged in compensatory roll tracking in a simulator. Aircraft dynamics were varied from easy to difficult, and the disturbance input was Gaussian noise with bandwidths of 0.25 and 0.5 rad/sec. Each run lasted two minutes, and each day a subject tracked the two input disturbance functions in a moving-base and a fixed-base simulation. Root-mean-square error was found to be the most sensitive metric of performance changes. For the easiest dynamics, static performance was better than moving-base. Performance became asymptotic for static runs on day 9 rather than day 13 for moving-base runs. This was attributed to backlash in the chair, and the presence of high-frequency motion that was disruptive to tracking. As the control dynamics became more difficult, however, the presence of motion cues clearly reduced tracking error. Moreover, learning time (days required to reach asymptotic performance level) was reduced for difficult dynamics when the simulation was moving-base as opposed to fixed-base.

KIRKPATRICK, M. and BRYE, R.G. *Man-machine evaluation of moving-base vehicle simulation motion cues*. NASA CR-120706, 1974.

The authors report on a motion cue investigation dealing with human factor aspects of high fidelity simulation carried out on the general purpose simulator at NASA's Marshall Space Flight Centre, Huntsville, Alabama. This

simulator has six degrees of freedom and a very sophisticated visual system. The aim was to provide additional general data on non-visual motion thresholds and to establish velocity change rates for specific use in washout technology in this simulator. Washout of translation or attitude rates in such a simulator involves contradictory cues since, during washout, appropriate visual cues (associated with a constant rate) would be available besides the motion cues. Since acceleration threshold studies have typically been conducted under visually impoverished conditions, the authors undertook to test the hypothesis that acceleration sensitivity would be reduced during a vehicle control task involving visual feedback, as compared with a condition where the subject is in darkness and making no control responses. Such a differential sensitivity effect would permit higher washout velocity change rates during actual vehicle simulation. The tests were carried out in pitch, in heave and in sway modes. The simulator was programmed to provide varying acceleration levels and the method of forced choice, based on the theory of signal detectability, was used to determine thresholds.

KOONCE, J.M. *Effects of ground-based aircraft simulator motion conditions upon prediction of pilot proficiency.* ARL 74-5/AFOSR 74-3 Parts 1 & 2, 1974.

The author was concerned with (1) transfer of training from the simulator to the aircraft as a function of the kind of simulator motion used and (2) the reliability of instrument flight checks given in a modified GAT-2 simulator and their predictive validity to performance in a Piper Aztec (twin-prop) plane. Each of three groups (30 per group) of IR pilots was tested on Day 1 and Day 2 in the simulator and on Day 3 in the plane. (The Day 4 flights had limited application). The three groups were treated identically except that Group I was tested with no simulator motion. For Group II the motion system was operated with its normal sustained banking and pitching. For Group III the motion system was modified to provide subliminal washout of banked attitudes during turns. An experimenter in the right seat and a second observer in the rear seat (both in the simulator and the plane) scored each subject's performances independently to allow calculation of reliability and validity coefficients, all of which were high. Flight check scores revealed that either type of cockpit motion makes a simulator easier to fly. Performances improved significantly from Day 1 to Day 2. All three groups showed positive transfer effects to the aircraft. However, the reliably disproportionate improvement by the "no motion" group strongly indicates differential transfer. Apparently pilots trained with simulator motion learn to depend on acceleration cues which they must learn not to depend on in the air because much airplane motion occurs at subliminal acceleration levels. The results indicate that the proficiency of pilots can be predicted to a high degree from simulated performance measures.

MATHENY, W.G., DOUGHERTY, D.J. and WILLIS, J.M. *Relative motion of elements in instrument displays.* Aerospace Medicine, 1963, 34, 1041-1046. CONTROLS AND DISPLAYS.

MATHENY, W.G., LOWES, A.L. and BYNUM, J.A. *An experimental investigation of the role of motion in ground-based trainers.* Final Report. Dec 1970-June 1973. NAVTRACQUIPCEN 71-C-0075-1, 1974.

The aim was to provide data relevant to the specification of motion requirements for flight trainers. Accordingly, 7 jet-qualified pilots aged 25 to 55 years flew the Tradec trainer (F4E aircraft model) under three conditions: (1) no motion (2) motion correlated with the output of the aircraft equations and visual displays and (3) random uncorrelated motion. Four bandwidths of correlated and three of uncorrelated motion were investigated. Both man-machine system output measures (e.g. altitude deviations) and operator output measures (e.g. stick movements) were used as measures of performance in studying the motion effects. None of the conditions effected significant changes in man-machine performance. However, significant differences were obtained among pilot performance measures for the conditions. With respect to pilot output performance (1) no differences were found between no motion and uncorrelated motion of high bandwidth (2) significant differences were obtained between the correlated motion conditions and both the uncorrelated and no motion conditions and (3) narrow bandwidth correlated motion was found to be equivalent to wide bandwidth. Recommendations are made for simulator design characteristics.

McLANE, R.C. and WIERWILLE, W.W. *The influence of motion and audio cues on driver performance in an automobile simulator.* Human Factors, 1975, 17, 486-501.

A highway driving simulator with a computer-generated visual display, physical motion cues of roll, yaw and sway, and velocity-dependent sound/vibration cues was used to investigate the influence of these cues on driver performance.

48 student subjects were randomly allocated to 6 experimental groups. Each group of 8 subjects received a unique combination of motion and audio cues. The control group received a full simulation, whilst the five other groups performed with certain combinations of motion and sound deleted. Each driver generated nine minutes of continuous data from which five performance measures were derived.

Results indicate that the performance measures of yaw, lateral and velocity deviations are significantly affected by the deletion of cues. Driver performance was augmented by the presence of motion cues, in that statistically significant negative correlations were obtained between the number of motion cues present and the measures of yaw and lateral deviation.

Recommendations are made regarding simulator design criteria in respect of motion and audio cues. For a driving simulator there should be (1) two, at least, of the three motions of yaw, roll and sway (2) a velocity-dependent audio cue.

MIDDLETON, D.B., HURT, G.J., BERGERON, H.P., PATTON, J.M., DEAL, P.L. and CHAMPINE, R.A. *Motion-base simulator study of an externally-blown flap STOL transport aircraft after failure of an outboard engine during landing approach.* NASA TN-D-8026, 1975. AIRCRAFT HANDLING.

MILLER, G.K. *A motion-constraint logic for moving-base simulators based on variable filter parameters.* NASA TN-D-7777, 1974.

The kind and amount of motion required in simulators is not well defined. In most cases the available travel of the motion base is small compared to that of the simulated manoeuvre. Consequently there is a need for a motion constraint or washout logic in order to avoid reaching the physical limits of the motion system. Using the Langley visual-motion simulator (six-degrees-of-motion freedom), the author has developed a motion-constraint logic for moving-base simulators entailing a modification to the linear second-order filters generally used in the more conventional approaches. In the modified washout logic, the filter parameters are not constant but vary with the instantaneous motion-base position to increase the constraint as the system approaches the positional limits. The primary advantage of the modified washout logic stems from the fact that the basic filter parameters can be chosen so that the resulting amplitude ratios are improved in the low-frequency range where the pilot's motion-sensing abilities are best. This improvement is achieved without a degradation in phase angle. In addition, accelerations larger than originally expected are successfully limited. Thus the modified washout logic can have the basic filter parameters scaled down for a particular task, and the few inadvertent spikes caused by the pilot while learning will not destroy the run. During simulated landing approaches of an externally blown flap STOL transport using decoupled longitudinal controls, the pilots were unable to detect much difference between the modified constraint logic and the logic based on linear filters with braking.

MILLER, G.K. and RILEY, D.R. *The effect of visual-motion time delays on pilot performance in a pursuit tracking task.* Proceedings of AIAA Visual and Motion Simulation Conference, Dayton, Ohio, U.S.A., April 1976.

This study concerns the effects of time delays added equally to the visual and motion channels of the Langley Research Center Simulator whilst pilots were engaged in a pursuit tracking task, with a regular target oscillation of 0.035 Hz, presented on the visual system of the simulator. Independent variables were (a) time delays in the range 0.047 to 0.547 sec (b) bad, basic or good simulated aircraft handling characteristics (c) the motion conditions, pitch, roll, heave and sway; pitch, roll and sway; pitch and roll and lastly fixed-base. Dependent variables were elevator and aileron control activity and total root-mean-square tracking error. A reciprocal tapping secondary task was also employed, but its effect is not reported due to erratic performance by pilot subjects.

The control of the bad aircraft showed a beneficial effect of full motion, as opposed to fixed-base, at the smallest time delay of 0.047 sec, and the simulation could not be run at greater time delays. The basic aircraft showed an increase in error when delay exceeded 0.172 sec fixed-base, but moving-base error did not increase until lag exceeded 0.297 sec. For the good aircraft, error increased when lag exceeded 0.172 sec, but lag of 0.422 sec could be tolerated when the simulation was moving-base. Collapsing over aircraft characteristics, tracking error did not increase until delay exceeded 0.172 sec for the pitch, roll and sway; pitch and roll and fixed-base runs. However error did not increase until delay exceeded 0.297 sec for the pitch, roll, heave and sway runs.

MORRIS, E. and MATTHEWS, N.O. *New visual and motion techniques in military flight simulation.* Proceedings R.Ae.S. Third Flight Simulation Symposium, London, England, April 1976. VISUAL CUES.

NEWELL, F.D. and SMITH, H.J. *Human transfer characteristics in flight and ground simulation for a roll tracking task.* NASA TN-D-5007, 1969.

Transfer characteristics for three pilots were measured in flight and in a ground simulator for a compensatory roll tracking task with small bank-angle disturbances. The forcing function in each case consisted of the sum of ten sine waves with a bandwidth of 1.5 radians/sec. A variable stability T-33 plane was used to obtain the flight measurements. Ground simulator measurements were with both the T-33 plane and a general purpose simulator which used a contact analogue colour display. Three different controlled elements were used - two of these were simple single degree of freedom elements that had previously been studied. The third was a multiple degree of freedom element representative of a plane with good handling qualities, and it was considered and controlled as a single degree of freedom configuration in roll. Only the multiple degree of freedom controlled element was flown in actual flight. Two techniques were used to generate the tracking task in the T-33 viz.,

- 1 the forcing function was injected directly into the display and
- 2 the forcing function was introduced through the aileron control system.

In flight, the first configuration had to be flown under IFR because the motion of the plane was not necessarily in harmony with the instrument-displayed motion. The second configuration was flown under VFR and the motion was in harmony with the visual display. In the contact-analogue simulator, the display approximated the VFR display of flight but there were no non-visual cues.

Results of the simple controlled element experiment agree well with previous results. For the multiple degree of freedom controlled element experiment, a noticeable effect of display was found. For this experiment, which was flown in a small disturbance bank-angle tracking task with good controlled element dynamics, non-visual cues appeared to be of less importance than visual cues. The three pilots exhibited similar adaptations to the controlled elements, although one pilot consistently used a higher gain in the T-33 ground and flight conditions than the other two. A full summary of the conclusions is too lengthy to quote in this synopsis.

PARRISH, R.V. and MARTIN, D.J. *Evaluation of a linear washout for simulator motion cue presentation during landing approach.* NASA TN-D-8036, 1975.

The comparison of a fixed-base versus a five-degree-of-freedom motion simulation of a B-737 aircraft performing ILS landing approaches was used to evaluate a linear motion washout technique. The fact that the pilots felt that the addition of motion increased the workload and this increase was not reflected in the objective results indicates that motion cues, as presented, are not a contributing factor to performance during landing approach. Subjective results from standard manoeuvring about straight-and-level flight for specific motion cue evaluation revealed that the longitudinal channels (pitch and surge) and, possibly, the yaw channel produce acceptable motion. The roll cue representation, involving both the roll and sway channels, was found to be inadequate for large roll inputs as used, for example, in turn entries.

PARRISH, R.V., ROLLINS, J.D. and MARTIN, D.J.Jr. *Visual/motion simulation of CTOL flare and touchdown comparing data obtained from two model board display systems.* Proceedings of AIAA Visual and Motion Simulation Conference (loose paper), Dayton, Ohio, U.S.A., April 1976. VISUAL CUES.

PIRANIAN, A.G. *The effect of the individual and combined stresses of vibration and sustained 'g' on pilot performance.* AGARD CP-145, 1975. HUMAN PERFORMANCE.

POULTER, R.F. and WILSON, R.V. *Pilot's assessment of a pitch motion system for a flight simulator.* IAM S-82, 1968.

#### *Objects*

1. To assess the pitch motion system of the IAM Hunter simulator and
2. To evaluate the flight plan used as an effective test of the motion system's capabilities.

#### *Subjects*

Eleven trainee test pilots from the Empire Test Pilots School, Farnborough, took part.

#### *Equipment*

The IAM Hunter cockpit. It could be flown either in fixed mode or with pitch motion.

#### *Method*

All the pilots were required to fly a set flight plan. They had the choice of using or rejecting the motion system. After the "flight" each pilot submitted a report, the contents of which were analysed for areas of consistent agreement.

#### *Conclusions*

1. Pitch motion improved the quality of simulation.
2. Pitch motion could be improved by removing the jerkiness of the simulator.
3. Rapid changes in attitude revealed the absence of a subjective feeling of acceleration forces as a limitation of the simple position system. The usefulness of a subjective assessment technique in the field of simulation is discussed.

RAGLAND, S., CHAMBERS, R.M., CROSBIE, R.J. and HITCHCOCK, L. *Simulation and effects of severe turbulence on jet airline pilots.* NADC ML-6411, 1964.

#### *Object*

To find out:

1. If an adequate simulation of the physical events displayed on the flight recorder of a United Airlines Boeing 720-B could be reproduced on a centrifuge simulator and
2. If there were any effects upon pilots flying under the same conditions detrimental to the safe control of the aircraft.

#### *Method*

The centrifuge was programmed to simulate turbulence-produced accelerations that fluctuated from a maximum of 3.5 Gz to a minimum of -2.0 Gz at a random frequency average of one cps. The pilot and the co-pilot who had flown the actual flight were the first to try the centrifuge simulation and they pronounced it excellent. Then eight other airline pilots and five local pilots each did a static run followed by a six minute simulated test.

#### *Results and Conclusions*

Effects upon pilot performance detrimental to safe control of an aircraft are thought to have been observed and recorded. It appears that there is a consistent tendency for the pilot to experience a kinaesthetic illusion which causes him to make inappropriate pitch control movements. When negative "g" was encountered for the first time, an initial movement of the stick in the wrong direction was the rule rather than the exception. Control activity differed widely between pilots. It was unrelated to specific periods of high turbulence. The use of shoulder harness as well as a lap belt made control easier and made the pilots feel more secure psychologically. There was some blurring of the instruments. However, if the pilot concentrated on the artificial horizon, he could maintain his orientation with regard to that instrument but he was unable to maintain a useful panel scan. Although the simulation lasted only six minutes in each case, it was obvious that the rate of onset of fatigue was much higher than in normal instrument flying. Disorientation was not a prominent feature in this experiment and motion sickness did not occur. No abnormal psychologic responses were encountered. The data suggest that, by responding to a strong kinaesthetic illusion of climb or dive after correcting from an unusual nose-up or nose-down attitude, pilots are creating ever-increasing deviations from normal pitch attitudes in both directions alternately, somewhat analogous to pilot-induced oscillations, until the aircraft stalls and falls off into a steep dive that is difficult to recognise or to recover from because of the limitations inherent in the types of artificial horizons frequently used in their aircraft.

RATHERT, G.A., CREER, B.Y. and DOUVILLIER, J.G. *Use of flight simulators for pilot-control problems*. NASA M-3-6-59A, February 1959.

Comparisons were made between flight results and results obtained with fixed-base and motion simulators over a wide range of flight characteristics. These results were used to study the importance of providing motion in a simulator in order that the pilot may operate it realistically. Regions of flight characteristics where motion stimuli are either mandatory or desirable are indicated.

RATHERT, G.A., CREER, B.Y. and SADOFF, M. *The use of piloted flight simulators in general research*. AGARD R-365, 1961.

A number of direct correlations between flight and various types of simulators have been examined in problem areas of interest for research on advanced transport and manned spacecraft. Where the characteristics are such that the vehicle is satisfactory or easy to fly, even the simplest forms of simulation are effective. The addition of motion cues is required in two general circumstances (1) where the motion cue helps the pilot by supplying a necessary lead or anticipation cue as in coping with a lightly damped or unstable vehicle or a sluggish system, and (2) where the motion cue realistically hinders the pilot in making a desired control motion as in using a very powerful or sensitive control system. Judgement of whether such cues will be needed in a given simulation can be made by inspecting the comparisons on the design-criteria charts in the reports referenced. If accelerations greater than about 4g are anticipated, they should be included in the simulation. However, all exaggerated or spurious motion cues encountered in a closed-loop operation on the centrifuge must be taken into account. Additional simulation sensors, such as measurements of performance and physiological condition and use of the human pilot analogue, are often a necessary supplement to the subjective opinion of the pilot.

RINGLAND, R.F., STAPLEFORD, R.L. and MAGDALENO, R.E. *Motion effects on an IFR hovering task: Analytical predictions and experimental results*. NASA CR-1933, 1971.

An analytical pilot model incorporating the effects of motion cues, and display and sampling was tested by comparing predictions against experimental results obtained from simulations. Three very experienced pilots "flew" VTOL hovering tasks in gusty air using separated instrument displays. The two experimental variables were the motion condition (fixed-base, moving-base with angular and linear cab motions and moving-base with angular motion only) and changes in vehicle damping. Display scanning behaviour was recorded on some of the runs. Performance and pilot opinion data were analysed relative to pre-experimental predictions. The scanning data was reduced and a few sample runs were analysed for pilot describing functions.

#### Conclusions

The results show that the pilot performs best when angular motion only is present – probably because a g-vector tilt cue is available to him in this motion condition. This provides an attitude indication even when he is not observing the attitude display. Vestibular threshold effects are also present in the results because of the display scaling, used to permit hovering position control within the simulator motion limits – washouts were not used in the drive signals. The IFR nature of the task results in large decrements in pilot opinion and performance relative to VFR conditions because of the scanning workload. The motion conditions are reflected in the scanning behaviour data. The readings indicate that pilots pay more attention to attitude control during fixed-base simulation than they do when motion is present.

ROLFE, J.M., HAMMERTON-FRASER, A.M., POULTER, R.F. and SMITH, E.M.B. *Pilot response in flight and simulated flight*. *Ergonomics*, 1970, 13, 761-768.

#### Object

To examine the effect of pitch motion on the fidelity of simulation.

#### Subjects

Nine RAF pilots took part.

#### Method

The technique used was to measure the pilots' responses in flight, find out if similar responses could be shown to be present in the simulator and if the presence of motion brought these responses closer to those obtained in flight. Accordingly, subjects' control activity, heart rate, respiratory rate and skin resistance were measured while they executed a set flight plan:

- (a) In a Hunter T-7 aircraft
- (b) In a Hunter cockpit trainer with pitch motion and
- (c) In the same trainer without motion.

Mean amplitudes of the control activity were calculated. Mean and deviations from a mean basal rate were found for heart and respiratory rates. The results were examined using Spearman rank correlation and Friedman analysis of variance tests.

#### Conclusions

1. The addition of pitch motion brought about changes in subjects' responses which indicated that the fidelity of simulation was improved.
2. Control activity and physiological response proved to be practical and informative methods of comparing flight and simulated flight conditions.
3. The comparison of intra-subject difference expressed in terms of deviations from a basal level was an effective method of handling physiological response.
4. Of the physiological responses examined heart rate was the most informative indication of similarities and differences between tasks and conditions.

5. Subject responses showed marked differences in the levels of basal activity and in the relationships existing between resting and working levels of response.
6. The appreciation of individual differences in both levels and mode of physiological response indicates that techniques should be considered whereby a summated index of physiological response can be derived.
7. Further experimentation using larger subject groups and more extensive methods of measurement should be undertaken using aircraft and simulators with the facility for providing a range of additional motion cues.

RUOCCO, J.N., VITALE, P.A. and BENFARI, R.C. *Kinetic cueing in simulated carrier approaches*. NTDC 1432-1, 1965.

*Object*

To find out if a motion system was beneficial in the simulation of a carrier-landing manoeuvre.

*Equipment*

An OFT trainer with pitch, roll and heave motion. This was supplemented by a visual display incorporating the remaining three degrees of motion modes.

*Subjects*

Twelve pilots with carrier-landing experience.

*Method*

Pairs of matched pilots were trained in the simulator in a carrier-landing manoeuvre. Two of the pilots did all their training with simulator motion. The remaining ten had varying amounts of static and kinetic training. All finished up with criterion "flights" which were carried out with motion present. Performance measures taken included pitch, roll, percentage of time outside the flight path, height "error", velocity and terminal flight data. The results were examined using analysis of variance and Student's t tests.

*Conclusions*

Kinetic cueing significantly improved performance in terms of percentage of successful landings, altitude "error", time outside the flight path and variability of pilot inputs. Most statically-trained pilots showed a decrement in performance which persisted throughout training and transferred to the criterion flights. Results indicate that kinetic cueing is a valuable and desirable adjunct to airborne simulation systems. The authors have included a related synoptic bibliography.

SADOFF, M. *A study of a pilot's ability to control during simulated stability augmentation systems failure*. NASA TN-D-1552, November 1962. AIRCRAFT HANDLING.

SADOFF, M., McFADDEN, N.M. and HEINLE, D.R. *A study of longitudinal control problems at low and negative damping and stability, with emphasis on effects of motion cues*. NASA TN-D-348, 1961.

The effects of incomplete or spurious motion cues on pilot opinion and task performance over a wide range of longitudinal short-period dynamics were investigated in flight and in simulated flight. Comparisons of centrifuge, pitch-chair and fixed-cockpit results with flight results indicated:-

1. The effects of spurious motion cues of the vestibular type on control-problem simulation were important only for high frequency lightly damped or moderately damped dynamics.
2. Of the three modes of simulation studied, the accurate angular acceleration cues provided by the pitch-chair compared the most favourably with flight conditions. For centrifuge simulation, which supplied accurate normal accelerations at the expense of introducing spurious pitching accelerations, pilots thought the effects much less realistic.
3. Overall, the results of all three modes of simulation could be extrapolated to flight conditions with a fair degree of accuracy.

Results of simulator studies with an analogue pilot replacing the human pilot are presented. It is shown that the pilots' response deduced by this method could be related to pilots' opinion, thus making it feasible to predict flight control problems analytically. During some centrifuge tests, a pencil-type side-arm controller was found to be markedly more effective than a conventional centre stick for high frequency lightly damped vehicle dynamics. By using the pencil controller, the pilot could apply precise inputs to minimise the adverse effects of large pitching and longitudinal accelerations.

SCHAUMBERG, G.F. and HEAPY, R.J. *Evaluation of an airseat as a limited cockpit motion system*. McDonnell-Douglas Corporation, Douglas Aircraft Company, 3855 Lakewood Blvd, Long Beach, California 90801, U.S.A. MDC J-0071, 1969.

*Equipment*

The DYNASEAT as used in this experiment is designed to produce a sensation of motion by computer-controlled air inflation of a compartmental seat and back cushion. The seat was fitted in a DC-9 fixed-base "all weather landing" simulator.

*Subjects*

Four DC-9 test pilots took part.

*Method*

The authors investigated the effect of the DYNASEAT on simulator fidelity and pilot performance during approach and landing sequences under various environmental conditions. These enveloped two seat conditions - seat operative and seat inoperative, two wind conditions - no wind and a fourteen knot cross wind, and three turbulence

conditions – no turbulence, light turbulence and moderate turbulence. After three preliminary trials, each pilot "flew" 36 approach and land runs presented in a random block design. The dependent variables, recorded from the beginning of each run until touchdown were:

- (a) The integral of the absolute "error" of roll command, and
- (b) The integral of the absolute "error" of pitch command.

The dependent variables regarded at touchdown were:

- 1. Sink rate in feet/second.
- 2. Pitch angle in degrees.
- 3. Roll angle in degrees.
- 4. Pitch rate in degrees/second.
- 5. Roll rate in degrees/second.
- 6. Longitudinal TD point, and
- 7. Lateral TD point.

In addition each subject completed a questionnaire. Performance measures were examined using a subjects x seat x wind x turbulence replicated analyses of variance test.

#### Conclusion

The subjective and objective results indicated that the DYNASEAT did not enhance approach and touchdown pilot performance nor did it add realism to the simulation.

SCHMIDT, S.F. and CONRAD, B. *Motion drive signals for piloted flight simulators*. NASA CR-1601, 1970.

Since the motion system of simulators is restricted by their mechanical drive, simulators cannot reproduce all aircraft motions (and hence motion cues) faithfully. In order to use the limited motion capabilities of a simulator effectively it is, therefore, necessary to (a) find out which motion cues are important to pilots (b) ascertain which cues are attainable within the drive capabilities and (c) synthesise logic for commanding motion which is both achievable by the drive system and realistic to the pilot. The authors set out a mathematical approach to this problem and they present logic for the Ames All-Axis Motion Generator. Their theory and logic may be applied to a wide variety of motion simulator problems.

SCHWEINFURTH, R. *Applicability of flight simulators with no visual or motion cues*. DGLR 70-070, 1970. In German. VISUAL CUES.

SHIRLEY, R.S. and YOUNG, L.R. *Motion cues in man-vehicle control*. IEEE Transactions on Man-Machine Systems, December 1968, MMS-9, 121-128.

This is an investigation of pilot adaptation in a simulated multi-loop VTOL hovering task with a disturbance input. Data for the operator's describing function has been obtained for a wide range of vehicle dynamics under conditions of visual cues only, roll motion cues only, and simultaneous visual and roll motion cues. Addition of roll motion cues to visual cues permits the operator to increase his phase lead at frequencies above 3 radians/sec. This makes it possible for him to increase the system open-loop gain without a loss of system stability, and thus to reduce the system tracking error.

SKANS, S. *The specification of requirements for flight simulation*. Proceedings of R.Ae.S. Symposium 'Theory and Practice in Flight Simulation', London, England, April 1976.

The simulator used for research, development or training is a peculiar tool in at least one respect – it should be more advanced than its counterpart aircraft. Normally it consists of six or seven subsystems. This paper deals with some criteria and specifications for two of these – motion and visual systems.

STAPLES, K.J. *Motion, visual and aural cues in piloted flight simulation*. AGARD CP-79-70, 1970.

An analysis is made of the part played by the various cues synthesised in simulators. Each cue is considered in turn with particular emphasis on the interaction with physiological sensors. Cues produced in the simulator are compared with those produced in flight to expose some deficiencies in the former. The effects of the substitution of one cue by another is also considered.

#### Conclusions

In training simulators, a high degree of fidelity is essential. Before doing a research project, the experimenter should match the simulator to the investigation in hand in the simplest possible way, while still retaining a sufficiently accurate representation of reality. Validation of the results is essential.

STARK, E.A. *Motion perception and terrain visual cues in air combat simulation*. Proceedings of AIAA Visual and Motion Simulation Conference, Dayton, Ohio, U.S.A., April 1976.

The author describes an evaluation of techniques to provide terrain visual cues and g-seat motion cues in the USAF Simulator for Air-to-Air Combat. Two pilots ran evaluation trials of take-off and landing, low-altitude ground attack and air combat using a contact-analogue type synthetic terrain generator. Detailed task-specific cues were added to this display as an Area of Interest using a film-based image generator. Cockpit motion cues were provided by a 6-df system.

Evaluation of the terrain visual cues was accomplished by means of pilot interviews. Conclusions concerning the requirements of the simulator for air-to-air combat simulation are presented under the following headings (a) altitude cues (b) heading cues (c) cues concerning rate of closure relative to the earth's surface (d) cues about range

and bearing relative to earth co-ordinates (e) attitude control cues (f) velocity control cues. Pilot evaluations of the g-seat were conducted involving a tow-target gunnery tracking exercise and a loop exercise. In addition to pilot interviews, some performance measurements were taken during the simulated flight. The g-seat provided cues to manoeuvres producing between 0 and 3 g. and was present in addition to the simulator motion system. It was found to make a contribution to the following areas of air combat simulation (a) zero-g manoeuvres (b) surge control (c) loop flying (d) maintaining constant pitch or turn rates (e) target tracking. In the absence of any cockpit motion, the visual cues produced feelings of motion and nausea, and control was erratic. The presence of simulator motion 'quickened' pilot response, and g-seat cues further quickened some responses.

STARK, E.A. and WILSON, J.M. *Visual and motion simulation in flying manoeuvring*. AIAA 73-934, 1973.

Pilot evaluations were made of an F-4 simulator with a six-degree-of-motion system, a terrain visual system, and a "g" suit. The evaluation manoeuvres required control close to the edges of the aircraft's aerodynamic and structural envelopes. Pilot comments indicated that very high fidelity is required in simulating marginal aircraft performance. Visual cues and motion in all six degrees of freedom are required to permit control without excessive instrument reference. Cues to g forces, sustained acceleration, buffet, and vibration are required to permit efficient control within structural limits.

STEWART, J.D. *Human perception of angular acceleration and implications in motion simulation*. AIAA 70-350, March 1970.

The Ames Man-Carrying Rotation Device was used to obtain threshold data for several stimulus durations, for three axes of rotation and for two response indicators. These thresholds indicate that the average pilot can be very sensitive to angular acceleration. First order approximations for response have been derived from four experiments and the resulting time constants vary from 4 to 10 seconds depending on the observer's task. It is shown that a simple static washout concept requiring continuous rotations at sub-threshold levels provides essentially useless reductions in simulator travel. Another washout scheme based on the dynamics of the vestibular system is considered. The variation in the apparent dynamics derived from the psychophysical data suggest that simulator washout characteristics may have to be tailored to each simulated flight configuration or piloting task.

STONE, R.W. *Ride quality - an exploratory study and criteria development*. NASA TM-X-71922, 1974.

The Langley six-degree-of-freedom visual motion simulator was used to measure subjective response ratings of the ride quality of eight segments of flight which, it was judged, would produce a wide and representative variation in comfort estimates. The results indicate that the use of simulators for this purpose seems promising. The author suggests criteria for ride quality ratings, based on psychophysical precepts.

STONE, R.W. *Simulator studies and psychophysical ride-comfort models*. NASA TM-X-3295, 1975.

A psychophysical model to predict ride-comfort was developed using flight and simulator data. The model presumes that the comfort response is proportional to the logarithm of the stimulus above some threshold value. To verify this concept of comfort modelling, the author had to obtain ride-comfort data for single degree-of-freedom random motions and for combinations of degrees-of-freedom random motions. Accordingly, a simulator programme was undertaken to measure subjective comfort response ratings using one degree, two degrees, three degrees and six degrees-of-freedom of motion. An analysis of the single degree-of-freedom and of the two degrees-of-freedom data is presented. Preliminary models of the ride-comfort response for single degree-of-freedom random motions and for certain combinations of two degrees-of-freedom random motions have been developed.

TREMBLAY, H.G., BROWN, J.L. and FUTTERWEIT, A. *Application of harmonic analysis in a study of tracking performance in a TV-2 aircraft and in centrifuge and stationary simulations of that aircraft*. NADC AC-6406, April 1964.

Piloting performance in a continuous tracking task was studied in an aircraft, in human centrifuge simulations controlled by a computer simulation of the aircraft, and in a stationary simulation. Continuous records of elevator and aileron control deflections were subjected to a power spectral density analysis.

#### *Conclusions*

Results indicate that there is a reduction in the contributions of high frequency components of power, successively, from the static simulation to the centrifuge simulations, to the aircraft itself. The power spectral density function for performance in a centrifuge simulation is more like that for the aircraft than is the power spectral density function in a static simulation.

WATERS, B.K., GRUNZKE, P.M., IRISH, P.A. and FULLER, J.H. *Preliminary investigation of motion, visual and g-seat effects in the Advanced Simulator for Undergraduate Pilot Training (ASUPT)*. Proceedings of AIAA Visual and Motion Simulation Conference, Dayton, Ohio, U.S.A., (Loose Paper). April 1976.

This study evaluated motion, field of view and g-seat factors in the ASUPT using two complicated experimental

designs which involved three instructor pilots. In the first design the independent variables were (1) three levels wind (2) three levels turbulence (3) two levels visibility (4) three levels simulator motion; fixed-base, pitch, roll and heave, and full six-axis (5) two levels of visual system field of view; plus and minus 150 degrees horizontal by plus 110 degrees and minus 40 degrees vertical versus a restricted view of 36 degrees vertical and 48 degrees horizontal (6) g-seat either off or on. In the second design, the independent variables were (1) motion and (2) turbulence as before (3) full field of view of visual system versus restricted field of view versus visual system off (4) g-seat on, off, or on with seat pan only operational. Dependent variables were mostly RMS deviations from criterion levels of flight parameters, also pilot power output measures. Subjects flew five representative manoeuvres. Results were analysed using analysis of variance, Tukey's test, and significant effects were considered when they not only produced F ratios significant at less than 0.1, but also accounted for more than 10% of the non-error variance. The results are complicated by interaction effects, and the authors themselves believe that extreme caution should be exercised in generalising from the simulator, tasks and subject population used. Briefly, no motion was found to be better than three degrees-of-freedom motion, with six degrees-of-freedom motion worst. Full field of view was better than restricted, especially for roll manoeuvres. G-seat presence aided especially pitch control in low-altitude flight. The report contains a full tabulation of treatment mean data.

WEMPE, T.E. *Effects of gust-induced and manoeuvring acceleration stress on pilot-vehicle performance*. Aerospace Medicine, 1965, 36(3), 246-255.

#### *Purpose*

The study was conducted to assess the effects of gust-induced and manoeuvring acceleration on pilot-vehicle performance during extended periods of LAHS flight.

#### *Subjects*

Two very experienced NASA test pilots and a commercial pilot took part.

#### *Equipment*

The Ames height control simulator (vertical accelerator).

#### *Method*

First, pilots familiarised themselves with the simulator. Then each did a sequence of test runs spread over several days. Each run consisted of a 60 minute sortie enveloping, sequentially, 10 minutes of flight in calm air, 40 minutes in turbulent conditions and 10 minutes in calm air. The task consisted of flying as closely as possible to a 250 feet clearance height above the terrain while viewing aircraft instruments and a display depicting the ground configuration ahead and below. The controlled variables were airspeed, cockpit motion, gust intensity, additional secondary tasks, the presence of a bending mode vibration near the visceral resonance frequency and the requirement for monitoring an automatic terrain-following system. Pen records of the flight path, induced acceleration forces, control activity, etc., were analysed to evaluate pilot performance.

#### *Conclusions*

1. The motion effects due to turbulence should be tolerable for up to 2½ hours for supersonic simulation and for up to 1 hour for subsonic simulation.
2. For fixed cockpit simulation the pilots were inclined to overcontrol slightly while maintaining a slightly better phasing with the terrain. The greatest difference between the fixed and moving cockpit control performance occurred during the practice sessions. When the pilots were first exposed to the terrain-following task the cockpit was fixed and there was a tendency for the pilot to induce large acceleration forces by extreme overcontrolling. However, when the cockpit was set in motion, this tendency immediately disappeared. During subsequent fixed-cockpit simulations interspersed with moving cockpit sessions, this tendency was apparent but in diminished amounts.
3. Wind condition had no apparent effect on terrain-following performance.
4. The author examined the remaining results in terms of intra-subject performance.

WILCOXON, H.C. and DAVY, E. *Fidelity of simulation in Operational Flight Trainers (OFTs). Part 1. Effectiveness of rough air simulation*. SDC 999-2-3a, 1954a.

The authors studied the effectiveness of turbulence simulation in basic instrument and radio range training in the SNJ OFT and the simpler NavBIT trainers. Turbulence consisted of mild pitching and rolling motion. Results showed that turbulence simulation adds realism to training but does not result in higher pilot proficiency in either the trainers or the SNJ aircraft.

WILLIGES, R.C., HOPKINS, C.O. and ROSE, D.J. *Effects of aircraft simulator motion cue fidelity on pilot performance*. Deutsche Gesellschaft für Ortung und Navigation, Nationale Tagung über Simulation im Dienste des Verkehrs, Bremen, W.Germany. Paper 1.2, April 1975. (In German).

The purpose was to find whether and how simulator motion cue fidelity varies with the desired application of a simulator. When the simulator was used for equipment design research, it was found that high fidelity washout motion (where rate of roll rather than bank angle is the input) produced results most akin to flight. When the simulator was used for pilot proficiency assessment, less realistic sustained motion (with the cockpit following a scaled-down linear analogue of bank angle after a certain time lag) provided pilot performance data of the highest predictive value. When the simulator was used as a training device for inference-referenced manoeuvres, the no-motion condition yielded as much transfer as either of the other simulator motion modes.

WILLIGES, R.C. and ROSCOE, S.N. *Simulator motion in aviation system design research*. ARL 73-6/ONR 73-2/AFOSR 73-3, 1973.

In three studies, the order of merit of four flight director attitude indicator displays (moving horizon, moving aircraft, frequency-separated and kinalogue) was assessed under three conditions of simulator motion (no motion, normal GAT-2 motion and washout motion) and the results were compared with flight performance. Comparisons among the studies were made to find whether performance on various display modes was differentially affected by simulator motion cues and, if so, what degrees and fidelity of simulator motion were required to produce results that generalised to flight performance. It was concluded that the presence or absence of motion cannot only affect absolute levels of performance, but different orders of merit among displays can occur. Specifically, inappropriate cockpit motion may be more misleading than no motion, whereas limited motion in pitch and roll corresponding closely to flight conditions may be sufficient to produce generalisable research data on the relative merits of flight displays. The effect of motion cues on pilot performance is complex and potential interactions among visual motion cues, workload, pilot experience and the degrees and fidelity of motion simulation need further investigation.

WILSON, D. *Advances in motion platform systems*. Proceedings of R.Ae.S. Symposium 'Flight Training Simulators for the 70s', London, England, October 1970.

Early research directed toward the physiological aspects of motion, in an attempt to define the minimum in simulation equipment required to provide successful transfer of information, led to the conclusions that:

1. only accelerations need to be simulated and
2. the rate of change of acceleration produces the significant sensory cue.

Since exact simulation of, for example, acceleration and weightlessness cannot be achieved except by having unlimited space, a compromise was reached in which an acceptable degree of motion simulation was obtained by rotating the pilot (in a cockpit) in the earth's gravitational field. In early experiments, Link used a pair of gimbals driven by motors to rotate the pilot in pitch and roll motion. The writer elaborates on the engineering techniques employed to produce the present six-degrees-of-motion freedom with varying payloads. Looking into the future he anticipates:

1. the addition of high frequency motion to pitch, roll and heave and
2. the collation of information relating to the physiological and psychological aspects of pilot response to motion simulation.

WRENNINGE, B. *A simulator investigation to find suitable command signals for a three degree-of-freedom simulator motion system*. Department of Aeronautics, Royal Institute of Technology, Stockholm, Sweden. 1967.

#### *Object*

To find how the motion system installed in a Dragon (J-35) simulator should best be commanded for the simulation of approach-and-land simulations for a Dragon aircraft.

#### *Subjects*

In the main part of the experiment, six experienced test pilots took part. All had flown the Dragon and all had simulator experience, though mostly in the fixed-base type.

#### *Method*

Preliminary "flights" were carried out to eliminate the motion equations giving the least realistic feel, and to establish the gains to be used in the subsequent test approaches. Then the six selected pilots compared the different suggested command signals and chose those which matched most closely the response of the aircraft. Each pilot was then required to "fly" two specific test approaches using each chosen equation of motion. One approach involved a correcting manoeuvre before the test approach was executed and the other was a normal approach. The axes of motion, evaluated one at a time, were:

1. heave (using two equations of motion)
2. roll (using four equations of motion) and
3. pitch (using three equations of motion).

Mean and root mean square performance scores were calculated, and the results were analysed by ranking, rating and correlation methods.

#### *Conclusions*

The work proved well worth-while because all the previously used command signals had to be modified in the interests of fidelity. It was found that pilots could easily be fooled when evaluating the flying qualities of the simulated aircraft, if the motion system command signals were unsuitable.

ZUCCARO, J.J. *The Flight Simulator for Advanced Aircraft (FSAA) - a new aeronautical research tool*. AIAA 70-359, 1970.

The author describes the FSAA. This simulator's motion system provides six degrees-of-motion freedom to a three-man transport-type cab. The motion system was designed to generate cues inherent in aircraft where the pilot's position is far forward of the centre of rotation of the aircraft, e.g. large jet and SST planes. To meet this requirement, an 80 feet lateral travel capability has been built into this simulator. Thus, a pilot may practice manoeuvres like lateral side-step during a landing approach and engine-out on TO. Research work done on the FSAA has included investigations relating to the development of improved handling qualities and airworthiness criteria for large jet transports.

## HUMAN PERFORMANCE

ADAMS, J.J., BERGERON, H.P. and HART, G.J. *Human transfer functions in multi-axis and multi-loop control systems.* NASA TN D-3305, 1966.

*Method*

Both the experiments were conducted in a fixed-base simulator. In the multi-axis tests, four NASA test pilots performed compensatory tracking tasks presented on a three-axis eight-ball display using a side-stick and rudder pedals for control. Two rate and two acceleration control systems were used. The pilots were tested in the pitch, roll and yaw axes separately, then in the combination of pitch and roll axes and finally in the pitch, roll and yaw axes combined. For the multi-loop tests a simulator was devised to represent the horizontal translation guidance system as used in lunar landings. Only horizontal translation was studied. The vehicle was controlled by moving the stick from side to side. Pilots and engineers did the tasks.

*Conclusions*

1. A pilot's response in multi-axis and double-loop control tasks can be well represented with linear constant-coefficient transfer functions.
2. Measurements made in multi-axis compensatory tracking tasks show that the pilot changes the response characteristics, and thus the representative transfer function, so that the closed loop system frequencies are reduced as the number of axes requiring control increases. These results can be correlated with a theory that the pilot has a given maximum information-processing capacity.
3. Two linear transfer functions, one for each loop, arranged in series are used to represent a pilot's response in a double loop control task. Measured gains from multi-axis tracking tests can be used in the inner loop. The gains for the outer loop pilot model are values that correspond to a system frequency much lower than those found in multi-axis tests. The gains for one particular control task are given in this paper.
4. These transfer functions can be used to give a quantitative description of system instabilities that result from unexpected vehicle dynamic changes such as damper failure. Also, the pilot transfer functions obtained from the multi-loop simulation can be used to provide useful design information.

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*Equipment*

The Minerva simulator at Smith's Industries Ltd., Cheltenham, England, is a well-equipped fixed-base simulator normally used for precision HUD work. For this experiment, only the HUD itself and the central control column were used.

*Summary*

Twelve RAF pilots performed a simulated flying task, six after loss of a night's sleep and six after loss of part of a night's sleep. Integrated tracking error scores showed no significant differences between the two groups. Peripheral light detection was significantly impaired by one night's sleep loss. Card-sorting and digit memory tasks showed no effects.

BRUGH, R.L. and McHUGH, J.G. *Flight simulator study of human performance during low-altitude high-speed flight.* TRECOM 63-52, 1963.

The authors report on the influence of LAHS flight conditions on the ability of pilots to perform surveillance-centred tasks. Six U.S. Army pilots and four Army observers flew about 278 hours on simulated three-hour missions involving five RMS gust intensity levels and two airspeeds. The flights were made in a moving-base simulator that had a vertical range of 12 feet and an acceleration capability of  $\pm 6g$ . Data was analysed in terms of human performance aspects of the missions.

CACIOPPO, A.J. *Pilot information utilisation: a study in human response dynamics.* Goodyear Aircraft Corporation, Akron 15, Ohio, U.S.A. Technical Report GER 7686, 1963.

*Equipment*

A cockpit mock-up with pitch and roll motion, a random noise generator to simulate turbulence in pitch, joystick control, a CRT, a GEDA computer modified to include a pilot analogue circuit and to present the dynamics of a jet-interceptor aircraft.

*Method*

The analogue model was first adjusted to match individual pilot control. Five jet pilots, three light plane pilots and one non-pilot performed a compensatory tracking task presented on a CRT. Control movements were recorded.

*Conclusion*

Pilots of limited experience used error rate as an important information source determining control behaviour. To the very experienced pilots, only error acceleration mattered.

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Pilots of limited experience used error rate as an important information source determining control behaviour. To the very experienced pilots, only error acceleration mattered.

CALLAN, W.M., HOUCK, J.A. and Di CARLO, D.J. *Simulation study of intra-city helicopter operations under instrument conditions to Cat 1 minima*. NASA TN-D-7786, 1974.

A fixed-base simulator study was conducted to define pilot workload and task performance associated with IF operations for an intra-city helicopter passenger service. Displays considered necessary to provide a minimal capability under IFR conditions were used to 'fly' a commercial helicopter route which was representative of the New York area, with each terminal assumed to be equipped with a precision approach guidance system. A cross section of pilots "flew" the route and, despite the high workload level, the results indicated that minima of a 200 feet cloud base and a half mile visibility were feasible.

CARBONELL, J.R., WARD, J.L. and SENDERS, J.W. *A queueing model of visual sampling: Experimental validation*. IEEE Transactions on Man-Machine Systems. MMS-9, 56-60, 1968.

The authors give the results of a validation study of an economic model of a pilot's visual sampling behaviour. The model is based on queueing theory. The validation is based on instrument and eye movement data obtained during mission flights using a Link trainer. The results of the simulation using the queueing model correlate well with the eye movement data. Characteristics of the model and results of the validation study are described, and suggestions for further study are discussed.

CLEMENT, W.F., HOFMANN, L.G. and GRAHAM, D. *A direct procedure for partitioning scanning workload with a flight director*. Proceedings of IEEE 'Cybernetics and Society' International Conference, Boston, Massachusetts, U.S.A., November 1973.

Eye-scanning measurements from simulated approaches in an instrument cockpit mock-up representing a contemporary jet transport have made it possible to simplify the procedure for predicting the partition of a pilot's scanning workload required for monitoring and controlling a task with status displays and a flight director. When there is only a single director control display, the new procedure eliminates iteration in the preliminary design computations. These computations are based on predictions of closed-loop input-correlated errors in displayed variables with respect to the trimmed flight values. Also included are methods for predicting multi-loop error coherence, and for correcting the predicted partition of scanning workload when the pilot's scanning remnant contribution is significant.

CORKINDALE, K.G.G. *A flight simulator study of missile control performance as a function of concurrent workload*. AGARD CP-146, 1974.

Eight pilots took part in a part-task simulation of the delivery of a stand-off air-to-surface guided weapon. The attack phase of a sortie was simulated. This phase lasted about 3 minutes and included a low level run to the weapon release area, weapon release, target detection on the TV monitor display and the aiming of the missile at the target. The four workload levels studied were: (1) missile control tasks only, (2) manual control of the simulator, (3) missile control tasks plus manual control of the simulator and (4) missile control tasks plus auto-pilot monitoring. The results showed that (1) performance at the missile control tasks was degraded by increases in concurrent workload, (2) manual flight and auto-pilot monitoring were adversely affected by concurrent missile control tasks. A small group of non-pilots produced a similar pattern of results but absolute levels of performance were predictably different. Eye movement and subjective data allow the two-task performance to be explained. The results of this study confirm laboratory secondary task experiments in that a deterioration in primary task performance is associated with the recurrence of a secondary task despite instructions given to the subjects to maintain the highest level of performance possible on the primary task.

CREER, B.Y., SMEDAL, H.A. and WINGROVE, R.C. *Centrifuge study of pilot tolerance to acceleration and the effects of acceleration on pilot performance*. NASA TN-D-337, 1960.

#### *Purpose*

To measure the effects of various sustained accelerations on the control performance of pilots seated in a flight simulator with a centrifuge in the control loop. A special restraint system was also tested and a comparative evaluation was made of a three-axis type of side-arm controller and a two-axis type, in combination with tow pedals for yaw control.

#### *Method*

The pilot performed his control tasks while being subjected to acceleration fields such as might be encountered by a forward-facing pilot on an atmospheric entry trajectory. Pilot opinion ratings and tracking error were used to assess the pilot's ability to control the system.

#### *Conclusions*

The study showed that there could be marked decreases in pilot tracking performance with increases in the magnitude of the impressed accelerations. Pilot comments indicated that, in order to have the same level of control over the vehicle, an increase in the vehicle dynamic stability is required with increases in the magnitude of the acceleration impressed on the pilot. The study indicated the improvement in tolerance to acceleration times which can be released through small changes in the pilot's restraint system. Pilot comments indicated a unanimous preference for the two-axis class of side controller over the three-axis class. The pedal controls used in this study resulted in effective yaw control for most acceleration fields investigated.

CROOK, W.G. *Development of low-cost cockpit/outside time-sharing training equipment*. FAA RD-72-95, 1972.

#### *Purpose*

To test the effectiveness of two pieces of low-cost time-sharing training equipment (Devices A and B) installed in a

ground trainer and in an aircraft.

#### *Equipment*

Device A consisted of a series of six small lamps individually wired and strategically placed on the windshield area of the plane and the ground trainer. Each light was lit automatically in a programmed random sequence. It stayed alight for 10 seconds and, provided he noticed it, the pilot was required to switch it off. A scoring unit automatically totalled the number of lights presented and how many lights were extinguished. The brightness of the lights was such that direct head-up vision was required to detect them. Device B was a self-contained aural signal transmitting unit which was activated automatically once a minute. Two frequencies were available, 400 Hz and 4,500 Hz. It was placed in the aircraft cockpit and served as a prompter to remind the pilot to conduct an outside scan for intruder aircraft. This unit did not have a counter.

#### *Method - Device A*

Twelve pilots each did two cross-country flights in the aircraft, a series of training sessions in the trainer and then two more flights in the aircraft. Certain control parameters, inside/outside scanning scores and light detection scores were obtained during these runs.

#### *Method - Device B - Aircraft only*

Three aural devices were loaned to three flight schools to evaluate their effectiveness under pilot training conditions. Pilots and instructors expressed their subjective opinion on questionnaire forms.

#### *Conclusions*

1. Time-sharing practice using a low-cost visual in-cockpit device is effective in improving a pilot's cockpit/outside visual search.
2. Two intensive training sessions in a ground trainer appeared sufficient to achieve significant visual scan improvement.
3. This pilot time-sharing training concept appears to be the most effective to date with the minimum of equipment.
4. The use of an in-cockpit aural warning device in the early stages of pilot training produced too much annoyance and distraction to be of significant benefit.

CURRY, R.E., YOUNG, L.R., HOFFMAN, W.C. and KUGEL, D.L. *A pilot model with visual and motion cues*. Proceedings of AIAA Visual and Motion Simulation Conference, Dayton, Ohio, U.S.A., April 1976.

The optimal control model of the human operator has been well validated in fixed-base, instrument flight situations. This paper describes the extension and evaluation of the model to account for the presence of motion cues and visual flight cues. A VTOL hovering task is used, and the model is found to give good agreement with empirical data. There is, however, a discrepancy between the model and the data at low frequencies.

CUSHMAN, W.H. *Cumulative flashblindness effects produced by multiple high intensity flashes*. Aerospace Medicine, 1971, 42, 763-767.

A study was made of the effect of high intensity ( $1.0 \times 10$  to the 8th mV) short duration (2 m.sec) light flashes in subjects seated in a simulator cockpit. Each trial consisted of one flash or a series of flashes with 15, 45, 120 or 300 secs between flashes. Flashblindness recovery times (RTs) for the ASI and the turn and bank indicator for simulated night-flying conditions were measured after the last flash of each trial. The RT for the ASI increased as the number of flashes was increased and, in most cases, decreased as the interflash interval was lengthened. The RT for the turn and bank indicator was unaffected by the number of flashes but increased slightly as the interflash interval was lengthened. The potential hazard of multiple flashes to air operations and the effectiveness of two countermeasures are discussed.

DAVIS, D.R. *Pilot error*. Air Ministry AP 3139A HMSO. 1948.

Over 350 pilots (predominantly RAF) carried out instrument flying exercises in a single-seat, fixed-base cockpit. The errors they made are described and their causes discussed.

#### *Results*

1. In general, the number of errors increased in the first half-hour of the test, were at a maximum in the second half-hour, and then declined.
2. As regards drugs, alcohol led to a marked deterioration of performance. The effect of amphetamine was variable but it tended to reduce deterioration caused by lack of sleep.
3. The effects of aircraft noise intensity were variable. Noise did not adversely affect performance accuracy but there were large individual differences in its effect on control movements.
4. The test performance was improved by forewarning pilots about the types of error they were likely to make.
5. The errors were explained as due to variations of anticipatory tension. Fatigue was not found to be a satisfactory explanation.
6. Pilots who showed marked inert reaction in the test were more often suspended from flying training subsequently, sustained more fatal accidents and more often became operational casualties than the rest. Also, those who showed marked errors of preoccupation in the test were more often suspended in subsequent training than the others.
7. The experimental results are considered in relation to flying. The hazards of flying, the training and selection of pilots, and the classification of the errors responsible for accidents are discussed.

DAVYDOV, V.V. *Psychophysiological features of the perception of instrument information by the pilot after diverting his attention to external features.* Voennno-Meditsinskii Zhurnal, November 1970, 50-53. (In Russian).

The time required for visual perception of instrument readings after viewing the outside world was studied in flight and trainer experiments on 15 pilots aged from 25 to 35 years. Cinematographic and electro-oculographic observations of eye movements indicated durations for which sight remained fixed on an instrument before the pilot took the necessary control action. Perception durations obtained for initial viewing of the instruments were compared with those after attention was distracted by external factors to establish possible differences caused by the combined effect of eye motion and optical accommodation. Results show that optical accommodation processes occasioned by switching from far to near-field viewing do not significantly affect the time for perception of panel readings in actual or simulated flight.

DREW, G.C. *An experimental study of mental fatigue.* FPRC 227, 1940.

140 pilots were tested in instrument flying using a static Spitfire cockpit containing the standard instruments and controls and a few essential extras. Every test lasted for two hours and was arranged, for convenience in scoring, in 7 units each comprising four separate manoeuvres of climbing, diving and turning. These units were arranged as follows (L indicates a period of straight and level flight); 1 unit, L2 and 3, L4 and 5, L6 and 7, landing and finish. Before starting, each subject practised until he could control the machine. Apart from the control courses outlined above, the conditions were changed for some groups in two ways. The first series was intended to check the reactions of fresh and tired pilots to kinaesthetic stimulation and consisted of three groups of men, each experiencing changes in pressure in the seat due to the inflation and deflation of football bladders under it, on two of the course units. The units chosen were 2 and 3 for the fresh group, 4 and 5 for the intermediate and 6 and 7 for the fatigued. The second series investigated the reactions of fresh and tired pilots to a difficulty introduced at the beginning or the end of the test — the instructions were recorded to form a more difficult intellectual exercise. These new instructions were substituted for the old on course 2 for the fresh group, and on course 6 for the fatigued. The results of the study are too lengthy to quote.

DYDA, K.J. and LEFRITZ, N.M. *Factors affecting pilot landing techniques.* NA-66-811, 1966.

*Object*

To study the landing characteristics of a delta SST and a variable sweep SST from the pilot's point of view.

*Equipment*

A moving-base jet transport cockpit fitted with an external visual display system.

*Method*

The experiment was performed in three stages, (1) a validation test, (2) handling qualities studies, and (3) the effect of pretest briefing:

1. *Validation programme.* Ten commercial airline pilots simulated a total of 1200 jet transport approach and landing runs. Eleven flight parameters were analysed. Pilot performance was compared to in-flight data. A high degree of correlation was found.
2. *Handling characteristics studies.* Five pilots completed 200 landings each in a delta SST cockpit and in a variable sweep SST cockpit. Pilot opinion ratings, pilot workload and pilot performance measures were obtained. Means and standard deviations were calculated.
3. *The effect of pretest briefing.* Seven pilots simulated a total of 765 approach and landing operations under two conditions. In the first series of "flights", the pilots were told the value of the backside gradient (reciprocal of airspeed) and frequency and damping conditions before each flight. In the second series, the pilots were aware that backside gradient and frequency and damping were the variables but they did not know the values used in any of the flights. Pilot opinion rating, column workload and performance measures were noted. In stages 2 and 3 pilot opinion ratings were correlated against workload.

*Conclusions*

Pilots concentrate on establishing a higher desired level of performance in controlling the vertical flight path in approach and landing more than on the lateral path. Improving the pilot's performance capability in the lateral axis did not alter his workload. Although the pilots need to know the kind of variable being studied, precise knowledge of their value and order of presentation can lead to erroneous pilot opinion ratings, performance and workload measures as well as erroneous correlation between these functions. Pilot ratings consistently correlated with column workload for the landing task in spite of the diversity of system characteristics and the environmental conditions imposed.

EYER, S.W. and IVERS, J.B. *The effect of alcohol upon Link trainer performance.* Naval Medical Research Institute, National Naval Medical Centre, Bethesda, Maryland, U.S.A. Project NM 001 056.06.01, June 1950.

*Equipment*

A modified US Navy 1-CA-1 Link trainer was used. Airspeed, pitch, degree of bank and rate of turn were recorded.

*Subjects*

Six volunteer seamen, inexperienced in Link trainer operation, took part.

*Method*

Two experiments were performed. Four subjects were used in the first. In the second six subjects were used, four of whom participated in the first experiment. Each subject was taught to operate the trainer by instruments until his performance became reasonably consistent. After the ingestion of whiskey the performance of each was tested. Of the four subjects in the first experiment, one showed a significant impairment of performance with a dosage of 60 ml of 86 proof straight Bourbon whiskey. In the second experiment, three of the six subjects showed impair-

ment of performance with 120 ml of 86 proof straight Bourbon whiskey. The authors discuss ways of improving methods of testing and scoring.

#### Conclusion

The Link trainer can be used to measure the effect of drugs on the performance of a skilled task under certain conditions. However, as used in these studies, it is too insensitive and the training of subjects for its operation is too time-consuming for its employment as a satisfactory laboratory instrument.

FRASIER, J.W., WHITNEY, R.U., ASHARE, A.B., ROGERS, D.B. and SKOWRONSKI, V.D. *G-suit filling pressures determined by seat-back angle*. *Aerospace Medicine*, 1974, 45, 755-757.

A series of closed-loop tracking experiments was carried out on the Dynamic Environment Simulator at Wright-Patterson A.F.B. using a specially constructed tilt-back seat. The seat pan and leg support positions were fixed. A computer-generated target aircraft and gunsight were projected to the subject on a CRT display. The subject's task was to centre the gunsight, using a side-arm controller, on the manoeuvring target aircraft. Performances were measured at levels of 4, 5, 6, 7 and 8 g with seat-back angles of 30 degrees, 45 degrees, 55 degrees and 65 degrees from the upright position (zero degrees). The results showed that g-suit pressures can be significantly reduced, without a deterioration in pilot performance, as the seat configuration becomes more supine.

GOLD, T. *Visual perception of pilots in carrier landing*. AIAA 73-917, 1973.

Experimental investigations were performed in a visual carrier-landing simulator to determine the accuracy and consistency with which pilots can judge position on the glide slope and flight path during final approach. The effects of ambient illumination, deck motion and the Flight Line Optical Landing System (FLOLS) visual aid were evaluated. Results, obtained with a novel psychomotor technique, indicate that pilots' mean assessments of position when on course, and flight path flying when flying towards the aim point, are precise. However, variability in judgements is high under all other conditions. Sensitivity to changes in position and flight path is low, particularly under the more demanding visual conditions.

GOLD, R.E. and KULAK, L.L. *Effect of hypoxia on aircraft pilot performance*. *Aerospace Medicine*, 1972, 43, 180-183.

Seven FAA IR pilots were exposed to three gas mixtures simulating ground level and altitudes of 12,300 and 15,000 feet. Performance was objectively measured while subjects flew ILS approaches in a GAT-1 trainer with pitch, roll and yaw motion. Significant decrements in performance were found at the 0.05 and 0.01 confidence levels at 12,300 feet simulated altitude and at the 0.005 level at 15,000 feet simulated altitude. It is concluded that supplemental oxygen is needed at or above 12,000 feet for any crew member involved in a complex task.

GRAHAM, W. and MANGULIS, V. *Results of a visual detection simulation experiment for the evaluation of Aircraft Pilot Warning Instruments (APWI)*. Final Report. Report available on AD classification number AD A-017023/5, 1974. Control and Display.

GREENING, C.P. and WYMAN, M.J. *Experimental evaluation of a visual detection model*. *Human Factors*, 1970, 12, 435-445.

The authors conducted a fixed-base simulation study to gather visual air-to-ground target recognition performance data for comparison with predictions made from the Autonetics Detection Model. A colour motion picture taken during a low-altitude flight was used to simulate an observer's forward view. To collect data on the widest possible range of target types, 108 targets were selected from the film. These targets were split into three groups of 36 to provide a reasonable recognition load for the subjects. Thirty male college students with a 20/20 near and far visual acuity field were divided into three equal groups. Each group was assigned one set of 36 targets. This provided a total of 10 encounters per target and 1080 encounters for the whole experiment. Observer performance was measured in terms of probability and range of correct target recognition. The Autonetics Detection Model uses parameters related to the target, the environment and the observer. In making predictions from the model, values of all parameters were specified independently of the experimental data. Curve fitting was not used to improve matching between the empirical and theoretical graphs. Results indicated a close relationship between the experimental data and the model predictions. A product moment correlation of +0.53, significant at the 0.1 per cent level, was obtained between the experimental and theoretical 50 per cent recognition ranges.

HALE, H.B., GARCIA, J.B., ELLIS, J.P. and STORM, W.F. *Human amino acid secretion patterns during and following prolonged multistressor tests*. *Aviation, Space and Environmental Medicine*, 1975, 46, 173-178.

As a feasibility study, two men were tested in a series of simulated flights. The design of the experiment was a factorial one. Psychological data was collected during a two-day baseline period, four 36-hour experimental

periods and four recovery periods. The experimental conditions were (1) uncomplicated simulator flight (2) flight complicated by extreme environmental dryness (3) flight complicated by mild hypoxia and (4) flight complicated by dryness and hypoxia. Throughout each flight, the subjects alternately worked two hours and rested for two hours, performing on psychomotor measuring devices during each work period. Five other men were studied under baseline conditions, and during a 48-hour simulated flight complicated by hypoxia. Urinary nitrogenous metabolites, including individual amino acids, were examined for sensitivity to the stressor complexes. Certain of the amino acids had higher stressor sensitivity, tending to differentiate the effects of the single, double and triple stressor complexes. They also differentiated the physiological states in the experimental and recovery periods.

HAMILTON, J.E. *F-101/F-106 flight simulator flashblindness experiment*. SAM TR-65-82, 1965.

Six pilots flew a F-101 simulator and eight pilots flew a F-106A simulator on a strike mission to find the effect of flashblindness on aircraft control. In addition, a study was made to find how much cockpit illumination is required to reduce flashblindness to a minimum recovery time.

#### Results

1. In 42% of the passes at the target, the pilot did not accomplish a programmed escape manoeuvre.
2. Instrument panel floodlighting immediately after the flash significantly reduced recovery time.
3. Floodlighting the panel with 300 ft-cdls did not significantly reduce recovery time above illumination at 100 ft-cdls.

HARPER, C.R. and KIDERA, G.J. *Aviator performance and the use of hypnotic drugs*. Aerospace Medicine, 1972, 43, 197-199.

The use of hypnotic drugs for sleep inducement has been avoided in the practice of aviation medicine. This caution has been based on the possible "next day" effects of the drug on flight safety and performance. This double-blind study design was to evaluate objectively and subjectively any performance decrement in a flight task after two nights of hypnotic drug-induced sleep. Thirty pilots performed 300 ILS approaches in a twin turbo-jet simulator. A Sanborne 8-channel recorder was used to measure flight parameters. Two drugs (glutethimide and flurazepam) and a placebo were used. The objective flight data indicate no significant decrement in performance greater than the placebo effect itself. Subjectively, flurazepam was superior to glutethimide, particularly in the hangover effect.

HARPER, C.R., KIDERA, G.J. and CULLEN, J.F. *A study of simulated airline pilot incapacitation*. Proceedings of Eighteenth International Congress 'Aerospace Medicine', Amsterdam, Netherlands, September 1969.

The authors report on the results of a study of the effects of simulated pilot incapacitation (involving an abrupt functional loss such as myocardial infarction or a cerebrovascular accident) on the behaviour of airline crews doing flight tasks. Twenty-five tests were conducted in a DC-8 simulator and twenty in a B-737 simulator. Three-man crews were used in the DC-8 tests and two-man crews in the B-737 studies. Results are given for different simulated altitudes and phases of flight at which "incapacitations" occurred. Observations and recommendations are given from operational and from medical human factor aspects.

HARTMAN, B.O. and SIMONS, D.G. *Fatigue effects in 24-hour simulated transport flight: Changes in pilot proficiency*. Aerospace Medical Association, 34th Annual Scientific Meeting, Los Angeles, California, U.S.A., May 1963.

#### Object

The effects of fatigue on aircrew proficiency was investigated using performance and psychophysiological measures.

#### Method

Each of four aircraft commanders spent 24 hours flying either a C-124 or a C-133 simulator in a series of eleven legs, each lasting about two hours and each terminated by an ILS landing. The study included continuous recording of pilot performance and biomedical monitoring throughout each 24-hour test. Six continuous measures of proficiency were taken, viz., aileron, elevator, rudder, altitude, airspeed and skid. Control movements were first differentiated (short time constant) to obtain the rates of change of control position and then integrated in 64 second epochs.

#### Conclusions

In general, the results showed that performance could be maintained for over 24 hours, that significant decrement in performance was more likely to be in the more complex cognitive functions, and that the loss in proficiency could be sudden and precipitous. The concurrent physiological measures (ECG, EEG, etc.) showed a gradual rather than a sudden change, suggesting that the maintenance of sustained proficiency was achieved at a measurable physiological cost.

HATTESTAD, B. and RIIS, E. *Measurement of performance in F-86 simulator*. Royal Norwegian Air Force Psychological Services of the Armed Forces, Oslo, Norway, 1967.

#### Equipment

An F-86K (Sabre) whole-task simulator.

#### Subjects

Eight pilots with Sabre aircraft experience took part.

#### Method

The experiment was performed in four parts.

*Part A* concerned the development of a standard flying programme. The pilot, using radar, was supposed to intercept an enemy aircraft.

*Part B* dealt with the effect of practice on performance of the programme. The pilots practised until they seemed to reach an individual maximum level.

*Part C* was concerned with the problem of how extra workload influenced performance.

*Part D* consisted of an experiment with one pilot flying the programme under the influence of alcohol.

#### *Findings*

No far-reaching conclusions have been drawn since only a small sample of subjects was used. It seems possible, however, to measure some aspects of flying performance under various conditions in a simulator. Pilots performed very well when exposed to extra workload of a routine character. Introducing new and unexpected conditions caused an obvious reduction in performance in some pilots. Flying in a hangover condition can be more dangerous than flying moderately intoxicated.

HENRY, P.H., DAVIS, T.Q., ENGELKEN, E.J., TRIEBWASSER, J.H. and LANCASTER, M.C. *Alcohol-induced performance decrements assessed by two Link trainer tasks using experienced pilots.* Aerospace Medicine, 1974, 45, 1180-1189.

Twelve USAF instructor pilots took part in an experiment using a GAT-1 trainer to investigate the degrading effects of ethanol on their performances of two separate tasks. The pilots were tested at three alcohol levels – 0.3, 0.6 and 0.9 gm. of ethyl alcohol per kg. of body weight, corresponding to blood alcohol levels of about 30, 60 and 100 mg. % respectively. Significant performance decrements were found for only the moderate and the high alcohol doses. The magnitudes of the decrements corresponded to those reported in previous experiments (Henry et al., 1974b) using the same test conditions, but with subjects who had no previous flying experience. An assessment of the operational significance of the performance-measuring scales was also attempted using questionnaires and by concurrent rating of performance by flight examiners. Only with the low alcohol dose could one be 95% confident that not over 5% of the pilot population would exceed the established limits.

Henry, P.H. et al. *Assessment of performance in a Link GAT-1 flight simulator at three alcohol dose levels.* Aerospace Medicine, 1974b, 45, 33-44.

HENRY, P.H., FLUECK, J.A., SANFORD, J.F., KEISER, H.N., McNEE, R.C., WALTER, W.H., WEBSTER, K.H., HARTMAN, B.O. and LANCASTER, M.C. *Assessment of performance in a Link GAT-1 flight simulator at three alcohol dose levels.* Aerospace Medicine, 1974, 45, 33-44.

To evaluate the effects of drugs and environmental stresses on pilot psychomotor performance, an automated system was developed on a GAT-1 trainer. Performance was electronically scored during 1-hour simulations of cross-country instrument flights using analogue and digital logic. The sensitivity of this system was assessed by observing the effects of three graded doses – 0.3, 0.6 and 0.9 gm. per kg. of body weight – of ethyl alcohol on scored performance. Three separate experiments were conducted using a total of twenty-two non-pilots aged between 21 and 29 years. Significant performance decrements were observed at all three dose levels. This experiment was repeated with pilots as subjects (Henry et al., 1974a).

Henry, P.H. et al. *Alcohol-induced performance decrements assessed by two Link trainer tasks using experienced pilots.* Aerospace Medicine, 1974a, 45, 1180-1189.

HENRY, P.H., TURNER, R.A. and MATTHIE, R.B. *An automated system to assess pilot performance in a Link GAT-1 trainer.* Final Report, March 1971–May 1973. SAM TR-74-41, 1974.

The authors have developed a prototype control and scoring system for the assessment of pilot performance in a GAT-1 trainer. This system automatically presents subjects with an hour-long series of manoeuvre instructions for a simulated cross-country flight on instruments in a single-engine light aircraft. Performance is scored electronically in terms of how closely subjects are able to stay within the tolerances prescribed for various instruments, as they execute the manoeuvres. Major components of this non-computer-based system are (1) two GAT-1 trainers (2) special display panels mounted in the cockpit of each trainer (3) a central control station (4) an assembly of special-purpose analogue and digital logic for error detection and scoring and (5) paper tape perforators for data logging. This report covers the basic design and the circuitry.

HILL, J.W. and GOEBEL, R.A. *Development of automated GAT-1 performance measures.* AFHRL TR-71-18, 1971.

#### *Object*

To develop an automated data recording and reduction technique for obtaining flight parameter correlates of pilot proficiency.

#### *Equipment*

A Link GAT-1 trainer connected to a Link-8 computer, enlarged to permit continuous monitoring of eight flight variables (airspeed, altitude, climb, roll, pitch, heading, glide-slope and localiser) and to supply signals for roll, pitch and heave simulation to the trainer.

#### *Method*

Thirty subjects were graded, according to their flight experience, into three equal groups. All familiarised themselves with the simulator characteristics. The experiment involved four tasks of increasing difficulty:

1. A holding task.
2. A holding task with power changes.
3. A five-part flight profile, and
4. An ILS landing approach.

In all, 266 measures were obtained for each of the 30 subjects. These consisted of means, standard deviations, correlations between variables and compensatory tracking gains and phase shifts. First, an analysis of variance on

the 266 variables was used to select the most influential ones. Then the selected variables were entered in a multivariate discriminant analysis to find which contributed most to differences in pilot experience. Although between 10 and 15 variables sufficed for perfect separation of the subjects into three experience groups, 27 variables significantly contributed to the separation. A single criterion variable, a linear weighted sum of these 27 flight parameters, is suggested as a measure of flight proficiency.

#### Conclusions

This study has shown that automated pilot performance measurement can be used successfully in objectively reflecting pilot proficiency. This confirms earlier research. Automated techniques like this are advantageous both for research and operations, in that they are objective, sensitive and entail a minimum of effort to use.

HOPKIN, V.D. and NAPIER, A.W. *Time estimation in a flight simulator*. IAM R-232, 1963.

#### Object

To study time estimation during a simulator task and to assess the adequacy of the simulator as a research tool.

#### Subjects

Four pilots and four simulator-naïve members of the IAM took part.

#### Method

The non-pilots familiarised themselves with the simulator. Then each subject was given a copy of a set flight plan incorporating eight manoeuvres. Each manoeuvre had a demanded (i.e. specified) time for completion. Subjects had to make their own unaided estimate of time while performing these manoeuvres. The entire flight plan had a demanded time of 40 minutes. Each subject performed the whole flight task twice. In one case he was instructed to take all the demanded time to complete each manoeuvre and to set his rate of change accordingly. In the other case he was told to complete the manoeuvres as quickly as possible and then to maintain that position until he thought the demanded time had elapsed since the beginning of the manoeuvres. Deviations from the demanded height, heading and time were used as performance criteria.

#### Conclusions

Time estimates were related to the complexity of the demanded flight manoeuvres, to the subject's previous experience with a flight simulator and to the instructions given, but errors in the time estimation did not relate systematically to the length of the demanded time. After less than two hours' practice, some non-pilots could follow the set flight plan as accurately as the pilots.

HUDDLESTON, H.F. and NAPIER, A.W. *Measuring pilot performance and control in a flight task simulator*. IAM T-226, 1964.

#### Subjects

One test pilot, one squadron pilot and one simulator-competent non-pilot.

#### Equipment

The IAM Hunter fixed-based simulator, a CRT display, an acceleration control.

#### Method

A computer-programmed tracking task was presented on the CRT display. The x-axis on the scope represented altitude and the y-axis, heading. After a short training session, each subject performed a 30-minute pursuit tracking task. All his control movements and instrument deviations were recorded on magnetic tape. Modulus integral elevator and aileron control motion beyond an arbitrary threshold were analysed in samples of 10-seconds duration.

#### Conclusions

The test pilot achieved the best performance primarily by maintaining a constant stream of small-duration control movements (nudges about stick centre). The pilot and the non-pilot achieved a satisfactory performance quite similar to each other. The pilot, compared to the test pilot, allowed larger errors to accrue and hence used generally higher amplitude control excursions which were maintained for longer times. The non-pilot used arduous near-random switching control movements of high amplitude and duration.

HUDDLESTON, H.F., NAPIER, A.W., POULTER, R.F. and SAMUEL, G.D. *Learning to track with an acceleration control in a simulated flying task*. IAM R-383, 1969.

#### Subjects

Twenty-four junior members of the IAM scientific and technical staff took part. None had previously used acceleration controls.

#### Method

The IAM Saunders-Roe fixed-base simulator was set up to represent a basic flying task. The task was presented on a twin-beam oscilloscope mounted top-centre of the simple instrument panel. The subject's primary task was to keep a moving spot on the CRT in the centre of a small circle. The spot was being driven slowly and unpredictably over the face of the scope. By manipulating a joystick the subject was able to control the movement of the pursuing circle. Each test lasted one hour. On the scope the x-axis represented altitude and the y-axis, heading. The subject's secondary task was to maintain airspeed at 300 knots. Among the performance measures obtained were height, heading and airspeed deviations, time on target, control and throttle activity and personality scores. Results were assessed using Pearson's product moment correlation, Wilcoxon's matched pairs test, Chi square test and the Mann-Whitney U test.

#### Conclusions

1. Subjects' scores on the personality tests related neither to mean performance nor control activity nor to changes in these parameters with time.
2. Measures of tracking error showed improvement and measures of control activity showed diminished effort

over the course of one hour.

3. Non-pilots behave in a fixed-base simulator in such a way as to make their data useless for human factors research into piloting problems. It is not easy to predict which subjects will be more pilot-like after initial training.

HUDDLESTON, H.F., NAPIER, A.W. and ROLFE, J.M. *Pilot familiarisation behaviour in a flight task simulator.* IAM R-331, 1965.

#### *Subjects*

One squadron pilot, one simulator-naive non-pilot, five student test pilots and three test pilot instructors.

#### *Equipment*

The IAM fixed-base simulator, audio and visual warnings, TV monitoring of subjects' instruments.

#### *Method*

Each subject was allowed 15 minutes to familiarise himself with the simulator. Then he was required to fly a set flight plan (lasting about 24 minutes) during which he had to acknowledge audio and visual warnings. Measurements included mean integral height and heading "errors" and a count of the number of displacements and time spent beyond arbitrary control limits.

#### *Conclusions*

Large individual differences in control activity scores were insignificantly related to performance. Elevator activity during familiarisation (where pilots explored height) was inversely related to scatter of warning response times. Aileron activity was also related inversely, but not significantly, to response times. Elevator activity correlated well from familiarisation periods to test runs. Aileron activity did not.

HURT, G.J. *Rough air effect on crew performance during a simulated low-altitude high-speed surveillance mission.* NASA TN-D-1924, 1963.

#### *Purpose*

The idea was to investigate the effect of turbulence on the performance of observers during a LAHS "flight".

#### *Subjects*

Thirteen NASA test pilots served as observers.

#### *Equipment*

The NASA normal acceleration and pitch simulator in conjunction with an analogue computer was used to simulate a vehicle flying through rough air at high subsonic Mach numbers. For this study the pitch mode was not used. A plotting board was used for navigational tasks. A Snellen chart was placed on the instrument panel and four more were placed beyond it.

#### *Method*

Initially each observer was given static and dynamic orientation flights. Then each was asked to fly in a sortie lasting from 11 to 14 minutes at high subsonic speeds in turbulent air conditions. Vehicle response levels in excess of the accepted human comfort level were imposed on the observers. During each sortie observers were asked to:

- (a) Read the instruments.
- (b) Read the eye charts.
- (c) Plot the course by hand, and
- (d) Respond appropriately to situation lights and switches.

Their performance was continuously monitored.

#### *Conclusions*

1. An observer is able to perform normal tasks during rough air flight.
2. Major changes in normal acceleration caused an interruption but did not stop the observer from performing the assigned tasks.
3. At the lower frequency amplitudes, an increase in the frequency of gust occurrence was more disturbing than small increases in the amplitudes of the accelerations.
4. There was no appreciable difference in the subjects' ability to read the Snellen charts.

#### *Recommendations*

- (a) Head restraint.
- (b) Proper grouping of the equipment to be monitored so as to require a minimum of head movement.
- (c) Malfunction and warning devices should be of such a nature as to demand the immediate attention of the observer.

IAMPIETRO, P.F., MELTON, C.E., HIGGINS, E.A., VAUGHAN, J.A., HOFFMAN, S.M., FUNKHOUSER, G.E. and SALDIVAR, J.T. *High temperature and performance in a flight task simulator.* FAA AM-72-7, 1972.

The effects of high cockpit temperature on physiological responses and performance were determined on pilots in a Link GAT-1 trainer. The pilots (all IR) "flew" an instrument flight at each of three cockpit temperatures, viz. 77°F, 110°F and 140°F. Each flight lasted about 50 minutes. Performance was scored as the deviations in heading from a predetermined flight path. Deviations were scored for seven segments of the flight. Physiological parameters recorded were heart rate, deep body temperature, skin temperature, urine output and sweat loss.

#### *Findings*

Deep body temperature increased 0.63°F at 140°F and decreased about 0.27°F during the neutral (77°F) run. Skin temperature increased 1.8°F during the 77°F run and 9.0°F during the hottest run. Heart rate increased

25 beats/min at 140°F, 18 beats/min at 110°F and 10 beats/min at 77°F. The largest body water loss was 300 gms. at 140°F. There were significant decrements in performance in three segments of the flight. Performance at 110°F was degraded over performance at 77°F during the first segment of flight. Performance at 110°F and 140°F was degraded over performance at 77°F during Turn 1. Performance at 140°F was worse than performance at 77°F and 110°F during the ILS segment. Results are discussed in terms of the complexity of the flight segment being "flown".

JANOWSKY, D.S., MFACHAM, M.P., BLAINE, J.D., SCHOOR, M. and BOZZETTI, L.P. *Simulated flying performance after marihuana intoxication*. Aviation, Space and Environmental Medicine, 1976, 47, 124-128.

All the subjects involved in this study had smoked marihuana socially for several years. Seven professional and three private pilots were trained to fly a specific flight sequence on an ATC-510 instrument flight simulator (Analogue Training Computers, Incorporated). The flight plan consisted of four consecutive 4-minute instrument holding patterns requiring a total of 16-minutes "flight time", and it included such typical manoeuvres as straight and level flight, turns, three-dimensional positioning and radio navigation. These tasks require psychomotor co-ordination besides such cognitive abilities as short-term memory, concentration and orientation in time and in space. The pilots then smoked, in counterbalanced order on a double blind basis, a social dose of marihuana (0.09 mg/kg delta-9 tetrahydrocannabinol) and a matched placebo. Then they "flew" the flight sequence. In contrast to the placebo, marihuana caused a gross decrement in flying performance, with increased prevalence of major and minor errors, altitude deviations, heading deviations and radio navigation errors. These effects persisted for at least two hours, and generally had disappeared by four to six hours after marihuana administration.

KATZ, S., ASE, P.K., RAISEN, F. and HILDENDORF, R.L. *Visual performance with simulated flaresight in artificial clouds*. Final Report. February-August 1969. AMRL TR-69-121, 1969.

This report describes a laboratory procedure for studying the effects of fog or mist on visual acuity under conditions of night illumination.

KLEIN, K.E., BRUNER, H., HOLTMANN, H., REHME, H., STOLZE, J., STEINHOFF, W.D. and WEGMANN, H.M. *Circadian rhythms of pilots' performance in a flight simulator and effects of time shift*. AGARD CP-61-70, 1970.

When a standard instrument flight in a supersonic simulator was repeated at intervals of two hours, the average performance of twelve pilots revealed a sinusoidal circadian rhythm curve with the temporal position of peak and trough between 2-3 p.m. and 4-5 a.m. respectively. After rapid transportation from Europe to the U.S. and back with a sojourn of 17 days (time shift = 8 hours), the duration of re-synchronisation was about 5 days on average for both directions with a rate of phase adjustment of about 1.5 hours per day. The change in the performance level following transit, dependent on the coincidence of the old and new clock time, was unequal during the course of the day, but in general the level was significantly decreased at day-time and increased during the late night hours. A performance decrement seen for the 24-hours total average, in comparison to the pre-flight control, was significant only after the eastward but not after the westward flight. The reason for this difference is mainly seen in a greater fatigue due to an unfavourable flight schedule and the more severe sleep loss connected with eastward travelling.

KRAUS, E.F. *A parametric study of pilot performance with modified aircraft control dynamics, varying navigational task complexity, and induced stress*. ARL 73-10/AFOSR 73-6/FAA 73-3, 1973.

Experiments were conducted in a Link GAT-2 simulator to evaluate the effectiveness of a system providing direct control over aircraft manoeuvring performance. Pilots performed complex navigational tasks involving the use of a computer-assisted area navigation system. Changing waypoint storage capacity of the simulated navigation system induced variable task loading on subjects. The experiment was replicated with and without a self-adaptive side task to find levels of residual attention associated with the control modifications and the varying workload levels. The system advocated yielded greater precision of manoeuvring control, fewer procedural errors, and an increased level of residual pilot attention. The side task proved to be a reliable discriminator to changes in workload associated with small changes in system design and task complexity.

KRENDEL, E.S. and BLOOM, J.S. *The natural pilot model for flight proficiency evaluation*. NTDC 323-1, 1963.

The incentive for this study was the need for a scientific method for flight proficiency evaluation, using simulators, by which success in actual flight could be predicted. The survey is based on a "natural pilot model" that identifies three criteria as being of prime importance to the understanding and measurement of pilot performance - consistency of system performance, human adaptability and least effort in skilled performance. Ways of quantifying these criteria and the implications to training are discussed.

MAIORIELLO, R.P. *Effects of pyrobenzamine and plimasin on fighter pilots flying a fighter intercept mission in the F4D flight simulator.* Aviation, Space and Environmental Medicine, 1975, 46, 1191-1193.

The F4D (Phantom) is a high performance tactical jet fighter-bomber with an intercept and air-to-air missile capability. Twenty-six F4D (two-pilot) crews from a Tactical R.A.F. Wing participated in a difficult intercept mission using an F4D simulator. They were divided into three groups, medicated with either plimasin, pyrobenzamine or a placebo. The group medicated with either plimasin or pyrobenzamine alone demonstrated decreased effectiveness in completing this intercept as compared with the non-medicated group. These medications apparently caused impairment of mission performance and should be avoided while performing flying duties.

MOORHOUSE, D.J. and JENKINS, M.W.M. *A statistical analysis of pilot control during a simulation of STOL landing approaches.* AIAA 73-182, 1973.

The authors have attempted to relate measurements of control activity to pilot opinion. Results are presented from a simulation of landing approaches of an externally blown flap STOL transport aircraft. The study concerned the influence of (1) glideslope angle at different approach speeds (2) pitch attitude response by varying pitch damping and control power (3) static margin and (4) lift curve slope. Statistical properties of the elevator activity were calculated and the results compared with standard pilot ratings according to the Cooper-Harper Scale. The RMS value of elevator activity shows a distinct relationship with pilot rating.

PIRANIAN, A.G. *The effect of the individual and combined stresses of vibration and sustained "g" on pilot performance.* AGARD CP-145, 1975.

A centrifuge, equipped with an F-4B (Phantom) moving-base cockpit was used to evaluate the influences of sustained normal accelerations, combined vertical and lateral buffet loads, and aircraft flying qualities on air-to-air tracking performance during simulated combat manoeuvring. Eleven test pilots tracked a moving target with a fixed reticle, centrally situated on the front windscreen. An all-attitude "outside world" view was provided in colour. Sustained normal accelerations from 1.3 to 5.0 g, buffet effects up to + or - 0.5 g, and lateral directional flying qualities were varied independently and in several combinations to assess their individual and combined influences on tracking performance. The latter was measured in terms of percentage time during which the target was within prescribed limits, projected miss distance from the target and in Cooper-Harper pilot opinion ratings.

#### Conclusions

1. Buffet intensities of up to + or - 0.5 g at a frequency of 10 cps have a negligible influence on tracking precision.
2. Sustained high normal accelerations of up to 5.0 g appreciably degrade tracking precision.
3. The influence of aircraft flying qualities was the greatest. Decreased dutch roll frequency and/or damping, adverse aileron yaw and proverse aileron yaw all have degrading effects on performance. Absence of aileron yaw resulted in optimum tracking.
4. Tracking precision can best be improved by (a) more pilot training under high normal accelerations and (b) improving aircraft stability at high angles of attack.

RAWSON, H.E. *Flight simulator study of human performance during Low-Altitude High-Speed (LAHS) flight.* ATRECOM TR-63-52, 1963.

#### Aim

To investigate the influence of simulated LAHS flight conditions on pilot performance of surveillance tasks.

#### Equipment

A moving base simulator with a total travel of 12 feet and an acceleration capability of  $\pm 6g$ , an associated analogue computer, a functional control system, CRT compensatory tracking equipment.

#### Method

Six US Army pilots and four Army observers (flying with the pilots) flew a total of 278 hours on simulated 3-hour missions involving five RMS gust-intensity levels and at two airspeeds. Control movements were recorded. Data was analysed in terms of pilot performance.

#### Conclusions

Controls should require fine, not large, movements (e.g. a joystick or rolling ball rather than a centre column) to overcome mechanical impairment of limb control.

ROSCOE, A.H. and GOODMAN, E.A. *An investigation of heart-rate changes during a flight simulator approach and landing task.* RAF TM-Avionics-155, 1973.

#### Equipment

The Blind Landing Equipment Unit Simulator at Bedford was set up with the handling qualities of the Comet 3B and with basic flight instruments as for the Trident 1. It was operated in fixed-base mode.

#### Method

Seventy-five pilots did over 800 runs to give them experience of approaches and landings in low visibility conditions. The opportunity was taken to measure their heart rates. The intention was to establish whether significant changes in heart-rate occurred due to:

- (a) the effectiveness of the simulator and
- (b) differences in the various approach conditions presented to the pilot.

This was found to be so for (a) but not for (b).

ROLFE, J.M., CHAPPELOW, J.W., EVANS, R.L., LINDSAY, S.J.E. and BROWNING, A.C. *Evaluating measures of workload using a flight simulator*. AGARD CP-146, 1974.

The authors describe an experiment in which an HS 125 (twin-jet) flight instrument trainer was used to evaluate questionnaire, performance and activity analysis measures of pilot workload. Attempts were made to distinguish between the physical, perceptual and mental components of workload. For this purpose three flight plans were devised of approximately equal duration, differing markedly with respect to the three above components. Six professional pilots flew eight flight plans and, after landing, completed questionnaires to assess the workload levels and the task content. During the flights video recordings were made of the pilots' manual and communication activity. Performance during ILS approaches immediately before and after the experimental flight plans was also measured. From these measures it was possible to obtain significantly different results relating to the different flight plans. These results were capable of distinguishing between the three components of workload represented in the flights.

SCHOHAN, B., RAWSON, H.E. and SOLIDAY, S.M. *Pilot and observer performance in simulated Low-Altitude High-Speed (LAHS) flight*. Human Factors, 1965, 7, 257-265.

#### Object

To investigate pilot and observer performance in piloting, navigational and surveillance tasks under simulated LAHS conditions.

#### Subjects

Six experienced pilots and four observers, who were also trained pilots, took part.

#### Equipment

The dynamic simulator used consisted of a one-man cockpit containing the usual flight controls, instruments and switches and a computer-driven terrain-tracking CRT.

#### Method

For the observers the stick movements were automatically controlled. Each pilot and each observer flew five 3-hour missions while coping in gusty conditions with check points, course changes and warning indications. Each mission consisted of an 80 minute cruise at 0.4 M, a 20 minute dash at 0.9 M and an 80 minute return cruise at 0.4 M. Performance measures were examined using mean and root mean square values, Student's t tests, Fisher's test and analysis of variance.

#### Conclusions

For pilots:

1. Flying ability decreased progressively as airspeed increased from 0.4 M to 0.9 M in turbulent conditions.
2. Intensity of vertical accelerations did not seem to affect flying ability except at the most severe levels. With a gust-velocity combination about 0.4 g RMS, instrument and visual flight were impaired and, here, a HUD and limb restraints would be beneficial.
3. Target identification was unimpaired by either turbulence or airspeed.

For observers:

1. They did less writing and more mental problem-solving as turbulence increased.
2. Target identification deteriorated as airspeed increased from 0.4 M to 0.9 M.
3. Gust intensity did not affect their observing ability. For both pilots and observers, performance efficiency on all tasks did not deteriorate from the beginning to the end of the missions though they did suffer from discomfort and fatigue.

SECKEL, E., HALL, I.A.M., McRUER, D.T. and WEIR, D.H. *Human pilot dynamic response in flight and simulator*. WADC TR-57-520, 1958.

#### Equipment

A Navion executive jet was used. A cruise speed of 120 mph was adopted as standard for all tests. For the simulator trials the same aircraft, stationary in a hangar, was connected to an analogue computer which generated the flight dynamics.

#### Summary

The authors have presented the results of an investigation to determine the difference in pilot tracking behaviour resulting from differences between flight and simulator control environments. They attempted to estimate the quasi-linear describing functions and linear correlations of several pilots when engaged in lateral and longitudinal tracking tasks with random-appearing forcing functions.

#### Conclusions

Statistical analysis of describing function and linear correlation data showed that:

1. Individual run phase angle (in deg.), amplitude ratio (in db), and linear correlation data are approximately normally distributed about the means for all runs.
2. The means of pilot's describing functions in longitudinal flight and simulator control show significant differences in both amplitude ratio and phase angle.
3. The means of pilot's describing functions in lateral flight and simulator control show significant differences in phase angle but no significant differences in amplitude ratio.
4. Significant differences between flight and simulator linear correlations were present for both lateral and longitudinal control.

5. The flight and simulator variances for lateral amplitude ratio and lateral and longitudinal phase angle were significantly different. No significant differences appeared between flight and simulator variances for longitudinal amplitude ratio and lateral and longitudinal linear correlation.

SHIPLEY, B.D., GERLAKE, V.S. and BRECKE, F.H. *Measurement of flight performance in a flight simulator*. Interim Report. AFOSR-75-0208TR, 1975.

Student performance evaluation is an essential part of effective instructional research. The evaluation of complex psycho-motor performances is difficult because the latter are typically transient. Performance in the simulator or in the aircraft reflects the difficulties stemming from the complexity of the task and from the transitory nature of performance. The authors describe a methodological study for the solution of these problems as applied to the assessment of students doing training exercises in the simulator.

SOLIDAY, S.M. and SCHOHAN, B. *Task-loading of pilots in simulated low-altitude high-speed flight*. Human Factors, 1965, 7, 45-53.

#### Task

To maintain a 500 feet terrain clearance and accurate navigation during a one-hour simulated sortie.

#### Subjects

Three pilots with flight experience ranging from 1,800 to 5,000 hours took part.

#### Equipment

A vertical accelerator containing an all-attitude indicator, a radar altimeter, a rate of climb indicator and a CRT which displayed a pitch angle command signal. (As long as the correct pitch command was maintained the aircraft was at, or was converging on, the 500 feet clearance altitude requirement). The simulator had a total vertical travel of 12 feet and an acceleration potential of  $\pm 6g$ . A jet aircraft in the light fighter or attack category was mechanised on the simulator's analogue computer.

#### Method

Three types of terrain, three airspeeds (0.4M, 0.7M and 0.9M), two navigation levels and three emergency task levels were combined into a  $3 \times 3 \times 2 \times 3$  factorial design. Each pilot flew each of the 54 conditions of the design, thus producing a total of 162 missions. The conditions were presented randomly to control order effects such as learning and fatigue. The RMS gust level was held constant throughout the study at 8 ft/sec, i.e. medium-heavy turbulence. Each mission was pre-programmed with respect to type of terrain and airspeed; to times, amplitudes and direction of heading changes; and to times and types of emergencies. Among the measurements noted were deviations from the 500 feet clearance altitude, heading errors, vertical accelerations and response times. Results were examined using averages, root mean square values, standard deviations, Duncan's multiple range test and analysis of variance.

#### Conclusions

1. Average clearance altitude throughout the flights did not vary with any of the experimental conditions. Pilots flew too high on "up slopes" and too low on "down slopes".
2. Deviations about the required clearance altitude:
  - (a) increased with increasing airspeed,
  - (b) increased with increasing steepness of slope,
  - (c) were unaffected by navigation or emergency procedures.
3. Heading maintenance and response times were equally good under all conditions.
4. There was no evidence of pilot fatigue throughout the study.

SOLIDAY, S.M. and SCHOHAN, B. *A simulator investigation of pilot performance during extended periods of Low-Altitude High-Speed (LAHS) flight*. NASA CR-63, 1964.

#### Subjects

Eight experienced jet pilots aged between 27 and 45 years took part. Their jet flight experience varied from 1,500 to 4,000 hours. All had LAHS flying ability.

#### Equipment

The tests were made in a simulator with a vertical range of 12 feet and an acceleration capability of  $\pm 6g$ . Rotational positions in pitch, roll and yaw were displayed on an all-attitude indicator.

#### Method

Each pilot made a 90 minute simulated sortie under 12 conditions enveloping two airspeeds, three gust levels and two types of terrain. The statistical design was a  $2 \times 3 \times 2$  factorial one. The conditions were presented in random order to counter effects such as learning and fatigue. Performance and physiological measures were recorded continuously during the "flights". Blood samples, drawn after certain flights, were studied to determine biochemical effects of flight stress.

#### Conclusions

Pitching "errors" made by pilots varied with terrain and airspeed, and increased when the vertical accelerations increased in magnitude. Altitude "errors" increased steadily as the gust-induced normal accelerations increased. Performance of the navigational task did not vary with terrain, airspeed or acceleration. Control stick displacement, frequency of control stick movement, heart rate and respiratory rate varied systematically with several of the experimental conditions. Changes in certain enzymes were detected which were sufficient to warrant further study as indices of LAHS stress. A pencil-type side-stick controller was more efficient than a conventional centre-stick. With the side-stick task performance deviations, total acceleration effects, heart rate and respiratory rate were reduced. However, fatigue effects with the side-stick were more pronounced than with centre-stick control. Pitch

augmentation affected only pitch "errors" and control stick movements. Transfer function coefficients varied with task complexity.

STAVE, A.M. *Effects of helicopter noise and vibration on pilot performance (as measured in a fixed-base flight simulator)*. NASA CR-132347, 1973.

The effects of noise and vibration on pilot performance are described. Pilot subjects were required to fly VTOL commercial IFR schedules using fixed-base simulation facilities. The routes flown simulated US metropolitan ones flown currently by a helicopter airline. Subjects were exposed to noise levels ranging from 74 db (ambient) to 110 db, and 17 Hz vibration stimuli ranging from 0.1 g to 0.3 g measured at floor level directly beneath the pilot's seat. Despite subject reports of extreme fatigue in these long flights, performance did not degrade. A curve of performance shows a slow improvement for the first three hours of exposure and a slight loss in performance during the remainder of the flight. As environmental stress conditions (noise, vibration and time in the simulator) increased, subject performance improved. Within the limits of this study the higher the stress, the better the performance.

SWANSON, A.M. *Notes on simulator instrumentation for measurement of pilot proficiency*. AFPTRC TM: OL-TM-57-3, 1957.

The author describes an investigation of the feasibility of obtaining pilot proficiency measures from oscillographic records of pilot performance in the B-52 simulator. A photon six-channel oscillograph was obtained to make preliminary tests in the study. The memorandum discusses the integration of the recording equipment with the flight simulator and the development of a plan for obtaining appropriate data to evaluate the utility of instrumentation in the measurement of pilot performance in the simulator.

VINJE, E.W. *An analysis of pilot adaptation in a simulator multiloop VTOL hovering task*. IEEE Transactions on Man-Machine Systems, December 1968, MMS-9, 110-120.

This is an investigation of pilot adaptation in a simulated multiloop VTOL hovering task with a series loop closure model. Using model equations, the pilot model parameters were computed from RMS hovering performance data measured in simulator experiments for a variety of VTOL aircraft configurations. Variations in the aircraft configurations affected both the aircraft's dynamic characteristics and its response to simulated turbulence. The pilots pitch-loop adaptation generally correlated with the frequency domain characteristics of the pitch response to turbulence and to control inputs. The results show no specific low frequency attitude gain requirements that must be satisfied by the pilot for the attitude disturbance and dynamic characteristics considered.

WEIR, D.H. and JOHNSON, W.A. *Pilot dynamic response to sudden flight control system failures and implications for design*. NASA CR-1087, 1968.

#### *Equipment*

Single and multi-loop tests were performed. For the single-loop experiments a static P-51 cockpit with centre-stick control was used. The roll dynamics were those of a Bell X14A airframe. For the multi-loop experiments a fixed-base cockpit was used with centre-stick control. A yaw rate augments was included so that the pre-failure Dutch roll dynamics could be varied over a region from poor to good.

#### *Method*

The dynamic response of the pilot was studied during sudden changes in the controlled element dynamics caused by flight control system failure.

#### *Results*

A model for the pilot's dynamic response is presented which accounts for his behaviour during the several phases of transition. The pilot's transition response and performance are improved if the difference in controlled element dynamics at failure is reduced.

WEIR, D.H. and McRUER, D.T. *Pilot dynamics for instrument approach tasks: Full panel multi-loop and flight director operations*. NASA CR-2019, 1972.

Measurements and interpretations of single and multi-loop pilot response properties during simulated instrument approach are presented. Pilot "flew" Category II - like ILS approaches in a fixed-base DC-8 simulator at the Ames Research Centre. A conventional instrument panel and controls were used with simulated gust and glide-slope beam-bend forcing functions. Reduced and interpreted pilot describing function and remnant are given for a pitch attitude, flight director and multi-loop (longitudinal) control tasks. The response data are correlated with simultaneously recorded eye scanning statistics. The resulting combined response and scanning data and their interpretations provide a basis for validating and extending the theory of manual control displays.

WEMPE, T.W. *Effects of gust-induced and manoeuvring acceleration stress on pilot-vehicle performance*. Aerospace Medicine, 1965, 36(3), 246-255. MOTION CUES.

WEWERINKE, P.H. and SMIT, J. *A simulator study to investigate human operator workload*. AGARD CP-146, 1974.

The experiment was aimed at a better understanding of human operator limitations in terms of control effort as included in the optimal control model. Response characteristics were studied in control situations of widely varying difficulty. Based on the experimental results, a control effort index is presented. The "predicted" control effort correlates excellently with subjective ratings and seems to have a useful generality.

WHITTINGTON, A.C. *An exploratory experiment to validate the use of heart-rate as a measure for inter-task stress in a piloted flight simulator*. RAE TM-Aero-1236, 1970.

When measured during periods of limited physical exertion, heart-rate (HR) may be regarded as an indication of the degree of the mental rather than the physical effort of a subject. In such circumstances the HR might show some correlation with the degree of difficulty of a given task. To test this hypothesis the HR of five pilots was measured in a heave, pitch and roll simulator, equipped with a visual system, during steep ( $6^\circ$ ) approach and two-segment ( $6^\circ$  and/or  $3^\circ$ ) approach tasks. The transition heights were 750, 500 or 300 feet and the cloud base varied between 200 and 1,500 feet.

#### Results

1. Comparing the  $3^\circ$  and  $6^\circ$  approaches using HR records alone, it appears that a greater degree of stress was experienced on the steep approaches because:

- (a) There was a greater variation in HR over the whole run for the  $6^\circ$  approach, and
- (b) The maximum increment in HR measures at TD was greater on the  $6^\circ$  approach.

2. Comparing the different transition heights on the two-segment approaches, a 300 feet transition height would appear to present, marginally, the most stressful situation of the three heights studied because:

- (a) The overall variation in HR is greatest on the approach with the 300 feet transition.
- (b) The maximum increment in HR recorded during the transition was greatest for the transition height of 300 feet, and
- (c) The variation in HR recorded during the transition was greatest for the 300 feet transition height.

These results agreed with the pilots' stated preferences.

3. There would seem to be little overall difference in stress factor between the straight-in  $6^\circ$  approach and the two-segment approaches. The overall variation in HR is about the same for both, although the average is slightly higher for the  $6^\circ$  approach. There is little difference in increment in HR at TD between the two types of approach.

4. Windshear conditions seem to present a more stressful situation. Areas where increased windshear correlated with heightened HR were found.

#### Conclusions

Continuous records of HR can provide a useful supplement to other measurements and to pilots' subjective comments on handling-qualities research.

WICK, R.L., BILLINGS, C.E., GERKE, R.J. and CHASE, R.C. *Aircraft-simulator transfer problems*. AMRL TR-74-68, 1974.

#### Equipment

A Cessna 172 (light aircraft) and a Link GAT-1 simulator were used.

#### Method

Five very experienced IR pilots flew 8 ILS approaches while under the influence of a placebo, 100 mgms and 200 mgms of secobarbital for a total of 24 approaches. During each approach, lateral and vertical angular deviations from the localiser centreline and glide path as well as IAS and deviations from the 16 kph command airspeed were continuously recorded. Immediately after these flights, replicate flights were carried out using the same pilots under the same conditions in the simulator.

#### Conclusions

A comparison of results demonstrates the simulator to be a more sensitive indicator of the effects of drugs than the aircraft. Some learning effects were noted in the simulator flights indicating that skilled airplane pilots are not necessarily skilled simulator pilots as well. The arousal effects associated with actual flight apparently compensated for some portion of the drug effect, leading one to the conclusion that there is still no adequate substitute for in-flight studies.

WILSON, J.M., ZEFFERT, H. and WILKEY, A.D. *The need for mock-ups and simulators*. Proceedings of R.Ae.S. Symposium 'Flight Deck Environment and Pilot Workload', London, England, March 1973.

Although in-service studies of pilot workload have great value, most workload analyses must be carried out on mock-ups and simulators in the interest of timeliness and economy. The mock-ups and simulators built for the Concorde programme and for initial V/STOL research are described in terms of design details and applications relative to workload analysis. The authors mention the use simulators and mock-ups will have in minimising pilot workload in future complex aircraft.

ZAITZEFF, L.P. *Aircrew task loading in the Boeing multimission simulator*. AGARD CP-56, 1969.

The Boeing Company's new multimission simulator, combining a 160° real-world visual display in high resolution colour together with a completely functional and correlated fighter attack cockpit, is described. Visual target acquisition performance was used as a measure of task loading in tests of one and two-man crews flying both realistically task-loaded missions and sequences requiring target acquisition only.

*Conclusion*

Visual target acquisition performance of two-man crews was significantly better than that of one-man crews in both types of flight.

## CONTROLS AND DISPLAYS

ABBOTT, B.A. and DOUGHERTY, D.J. *JANAIR - Contact analogue simulator evaluation: Altitude and ground speed judgements*. BHC D-228-421-015, 1964.

The purpose was to determine the accuracy with which altitude and ground speed could be interpreted from a JANAIR vertical display. The display presentation was open loop (no control task was required of the subjects). Relevant manoeuvre variables were presented on the display including heading, ground speed, rate of turn, vertical speed and altitude. From an analysis of the results, recommendations for the re-design and use of this type of display are made.

AIKEN, E.W. and SCHULER, J.M. *A fixed-based ground simulator study of control and display requirements for VTOL instrument landings with a decelerating approach to a hover*. Final Report. Calspan Corp., Buffalo, New York, U.S.A. CALSPAN AK-5113-F-2, 1974.

An exploratory study of the control and display requirements for performing decelerating transition landings on instruments with the X-22A aircraft was conducted using the X-22A fixed-base simulator. This experiment was prerequisite for an in-flight VTOL transition landing programme using the variable stability X-22A aircraft. Both full and partial transitions to a hover were flown along a 10 degree glide path at deceleration levels of up to 0.1 g. Various control/display system combinations were designed, developed and evaluated for the task. Two specific objectives were to investigate the benefits of a direct velocity control system as opposed to the normal X-22A thrust controls, and to determine the feasibility of adapting, through electronic rather than mechanical means, the X-22A duct rotation system to direct velocity control.

AMMERMAN, L.R. *Evaluation of an integrated electronic instrument display for helicopter hover operations using a six-degree-of-freedom fixed-base simulation*. AD A010834, 1975.

The author discusses the development and evaluation of an integrated instrument display designed to lighten the workload and improve the control, during precision hovering, of pilots flying solely on instruments. He uses a hybrid computer system to implement a six-degree-of-freedom fixed-base simulation of the SH-2F Helicopter and a graphics processor to generate the integrated instruments display. Pilots were asked to rate the integrated display against conventional flight instruments after flying a simulated night, over-water rescue mission. The study revealed that the simulated aircraft dynamics were susceptible to pilot-induced oscillations in hover and, therefore, unsatisfactory for use as an evaluation tool. In general, pilots preferred the integrated display. However, further study is recommended because meaningful quantitative results were not obtained.

ANNIN, G.D. *The influence of piloted flight simulator studies on the design of the SST instruments*. SAE 670306, 1967.

The author demonstrated that, with the help of simulator training and some supplementary flight, the aircrew could successfully manage the Boeing SST, given minor improvements to the conventional instruments and flight deck equipment. However, advanced display techniques employing cathode ray tubes, optical projection, and time-sharing devices could be used in the simulator to promote better flight management, reduced crew workload and easier interpretation of altitude, speed and navigation information. The author describes simulator investigations which have yielded tentative solutions to three instrumentation problems, viz.,

1. The optimum scale factor for the pilot's pitch indicator,
2. The economical evaluation of experimental landing displays through the use of CRT line-writing techniques, and
3. The development of a display system for informing the pilot of his situation with respect to a prescribed sonic-boom-limited climb or descent profile.

BATY, D.L. *Evaluating a CRT map predictor for airborne use*. IEEE Transactions on Systems, Man and Cybernetics. SMC-6, 209-215, 1976.

Six airline pilots took part in a fixed-base simulator experiment designed to study the advantages and disadvantages of incorporating a simple horizontal flight path predictor on both fixed and rotating electronic CRT map displays. The pilots were asked to fly a figure eight ground track whilst attempting to maintain constant altitude. All flight information was displayed on one 17-inch CRT monitor. The independent variables were map orientation, pilots, presence or absence of crosswinds, presence or absence of gusts and presence or absence of predictor. Error scores were recorded as deviations from the commanded ground track and altitude. It was found that the predictor reduced deviations from the commanded ground track, narrowed performance differences between pilots and decreased pilot workload.

BATY, D.L., WEMPE, T.E. and HUFF, E.M. *A study on aircraft map display location and orientation*. IEEE Transactions on Systems, Man and Cybernetics. SMC-4, 560-568, 1974.

Six airline pilots took part in a fixed-base simulator study to determine the effects of two horizontal situation map display-panel locations relative to the vertical situation display, and of three map orientations on manual piloting performance. Pilot comments and opinions were formally obtained. Significant performance differences were found between wind conditions and among pilots, but not between map locations and orientations. The results

also illustrate the potential tracking accuracy of such a display. Recommendations concerning display location and map orientation are made.

BERGSTROM, B. and HUDDLESTON, H.F. *HUD evaluation by limited flight simulation: Simplified SAAB 37 and Specto Kestrel aircraft displays*. IAM R-398, 1967.

#### Aim

The purpose was to evaluate the Viggen (simplified SAAB 37) and the Kestrel HUDs from the pilot's point of view using a single-seat fixed-base simulator. The displays differ in that the Viggen gives some information of aircraft position relative to the desired flight path and the ground, whereas the Kestrel display is basically a flight director display. Additionally, the Viggen display employs integrated height information while the Kestrel display uses a peripherally positioned digital height readout. The approach was to find out how the two displays differed

1. as regards the pilot's overall performance under increasing workload and
2. as regards the pilot's height orientation under increasing workload.

#### Equipment

The cockpit was fitted with a control stick, throttle and a HUD but it did not contain the conventional flight instruments. A secondary task indicator was placed at 90 degrees to the left of the pilot's line of sight. This task involved looking aside at the indicator in response to a tone and doing simple arithmetic. Two buttons on the control stick were used for secondary task responding.

#### Method

Eight squadron pilots each flew ten 16-minute simulated sorties to evaluate the alternate displays. The pilots performed three tracking tasks – height, heading and airspeed – continuously and they reported height at intervals. The manipulation of a secondary task was used to induce controlled levels of workload.

#### Findings

No detailed conclusions could be drawn on relative performance between the two displays, presumed tracking differences being masked by technical difficulties in data collection. An analogue height display yielded rating errors that increased with height, whereas a numerical display gave rise to constant errors.

BERINGER, D.B., WILLIGES, R.C. and ROSCOE, S.N. *The transition of experienced pilots to a frequency-separated aircraft attitude display*. Human Factors Society 18th Annual Meeting, Huntsville, Alabama, U.S.A., October 1974.

Twenty-four experienced pilots were given one flight in a Link GAT-2 simulator and one flight in a Beechcraft C-45H plane using either a moving horizon, moving airplane or frequency-separated attitude display. The tasks included recovery from unknown attitudes, disturbed attitude tracking and completion of an area navigation course. Data collected in the C-45 H aircraft demonstrated superior performance of both the frequency-separated and moving horizon displays when compared to the moving airplane display during unknown attitude recoveries. The frequency-separated display was superior to all others during disturbed attitude tracking. It was concluded that the performance of experienced pilots during their initial training to a frequency-separated flight attitude presentation is at least comparable and possibly superior to their performance with the conventional moving horizon presentation.

De BILLIS, W.B. *Flight information scale test for heads-up and panel mounted displays*. Human Engineering Laboratories, Aberdeen Proving Ground, Maryland, U.S.A. HEL-TM-22-73, 1973.

#### Flight information scale test for heads-up and panel mounted displays

Scales designed to provide altitude, airspeed and heading information were combined into six display formats for heads-up and panel-mounted applications. Twelve US Army pilots flew each format under static base simulation conditions. The subjects responded to the displays by providing a cyclic control stick response to various scale value changes. Response time and incorrect control motion were used as dependent variables. Results of this experiment tend to indicate that considerable leeway in scale design is permissible without causing significant difference in pilot performance as measured by the dependent variables. The only statistically significant comparison occurred between the best and worst formats. On a moving thermometer tape display, pilot performance was significantly lower. This difference was the result of scaling requirements rather than scale type.

BRIGGS, G.E. and WIENER, E.L. *Fidelity of simulation: I. Time-sharing requirements and control loading as factors in transfer of training*. NTDC 508-4, 1959.

To determine the effect that fidelity of simulation of a training device has on transfer of training as a function of the complexity of the task, 48 undergraduates took part in a two-dimensional control task which simulated an interceptor aircraft operation. Transfer of training was measured as a function of control loading (spring stiffness present in a control column) and peripheral time-sharing requirements (number of simultaneous dimensions of control required). Each subject had 24 training trials followed by 8 transfer trials.

#### Conclusions

1. With a high level of time-sharing, subjects trained with minimum force cues achieved less transfer to a situation characterised by optimum force cues than did subjects trained under a low level of time-sharing.
2. Time-sharing requirements tended to increase the importance of proprioceptive information or "control feel" in a two-dimensional compensatory tracking task.

BROCKER, D.H. and GANZLER, B.C. *HUD for the Flight Simulator for Advanced Aircraft (FSAA)*. NASA TM-X-62416, 1975.

A HUD for a V/STOL lift-fan transport simulation study is described. The pilot's visual flight scene had the HUD optically superimposed over the usual outside world video flight scene. The flight director display required the

development and integration of a flexible programmeable display generator, graphics assembler, display driver, computer interface system and collimating optics to provide the pilot's flight scene. The optical overlay was realistic because both scenes appeared at optical infinity, and the flexibility of this display establishes its value as a research tool for use in future simulation programmes.

CARLSON, E.F. *Direct Sideforce Control for improved weapon delivery accuracy*. AIAA 74-70, 1974.

The Direct Sideforce Control System (DSFC) allows the pilot to make rapid precise heading changes in a wings level attitude with zero sideslip. It can also trim out crosswinds. The effectiveness of the DSFC for the air-to-ground weapon delivery task was evaluated on the NASA-Ames FSAA large amplitude moving-base simulator. This has shown that the DSFC can reduce the weapon-miss distance by a factor of three over that for a conventional control system. The pilots who flew the simulation felt that the lateral accelerations developed by the DSFC would not pose a problem.

CROSS, K.D. and CAVALLERO, F.R. *Utility of the vertical contact analogue display (VCAD) for carrier landings: A diagnostic evaluation*. AGARD CP-96, 1972.

#### *Subjects*

Six carrier-qualified pilots aged from 25 to 32 years and with flight experience varying from 300 to 3700 hours together with six laboratory staff took part.

#### *Equipment*

They flew a fixed-base model of a F-4 (Phantom) aircraft mechanised on a Beckman analogue computer. The VCAD, a pictorial vertical situation display generated by a digital computer and presented on a CRT, was the primary flight control instrument. It featured reference lines for pitch, roll, heading, and vertical, horizontal and longitudinal position.

#### *Method*

The aim was to evaluate the accuracy with which simulated carrier landings could be performed using the VCAD. A secondary objective was to generate diagnostic data to define the relative magnitude of different potential contributors to total system error. Position and attitude errors were measured under each of five experimental conditions – a full-scale simulated carrier landing task and four part-task simulations. The part-tasks were designed to assess the degree to which display resolution, temporal loading and control complexity contribute to total error.

#### *Conclusions*

The results revealed that all three attitude parameters were controlled extremely accurately under all conditions. Control of vertical and lateral position in the full-scale simulation was accomplished with the same precision as for daylight carrier landings in a F-4 plane. The part-task data revealed that the largest contributor to lateral error was control complexity. Display resolution and temporal loading were large and about equal contributors to vertical errors.

CURTIN, J.G., EMERY, J.H. and DRENNEN, T.G. *Investigation of manual control in secondary flight tracking tasks*. Annual Technical Report. McDonnell-Douglas Aerospace Corporation, Louisville, Montana, U.S.A. MDC E-0890, 1973.

Four radar control types were evaluated for a target acquisition and tracking task as part of a research programme directed at control simplification. Control variables included type of control action (displacement or force), location (integrated into throttles or independent) and personal equipment (gloves or no gloves). The four controls were compared for a simulated air-to-ground weapons delivery mission involving two navigation segments and a target-tracking phase. Sixteen pilots served as subjects. The experiment was performed in a part-task, fixed-base simulator with equipment akin to a current attack aircraft. A PDP-12 computer was used with the necessary interface software and accessories. Target acquisition and tracking data, time on target, deviations from pitch and roll command and airspeed control were measured.

EDENBOROUGH, R.A. and HAMMERTON-FRASER, A.M. *A flight simulator comparison of two methods of displaying altitude and vertical speed information*. IAM R-397, 1969.

#### *Object*

To assess presumed differences between two methods of displaying altitude and vertical speed information using behavioural and physiological dependent variables as measures.

#### *Method*

Using a Hunter fixed-base simulator, eight jet-qualified pilots flew two sorties, one with a separate altimeter and vertical speed indicator and the other with a combined instrument which consisted of:

- (a) A digital display providing an indication of height to the nearest 50 feet.
- (b) Mounted beneath (a), a sensitive vertical speed indicator displaying vertical speed to  $\pm 4,000$  feet/min.
- (c) Mounted alongside the above two displays, a vertical presentation indicating gross height from 0 to 60,000 feet.

Technical difficulties resulted in the loss of performance measures for four pilots. The performance measures taken during the study were:

1. The square of the deviation from the prescribed height.
2. The square of the deviation from the prescribed heading.
3. The square of the deviation from the prescribed airspeed.

The control activity measured was:

1. Elevator amplitude, and
2. Elevator duration.

The physiological measures obtained were:

1. Leg and arm EMGs recorded in arbitrary units and integrated over 10 sec epochs.
2. Respiratory rate in terms of the number of breaths per 10 sec epoch.
3. Respiratory volume in litres x 100/2 per 10 sec epoch.
4. Heart-rate in beats per 10 sec epoch.
5. Skin resistance in kilohms integrated over 10 sec epochs.
6. End tidal CO<sub>2</sub> as a percentage of CO<sub>2</sub> at the end of expiration, integrated over 10 sec epochs.

Using a questionnaire form, the authors attempted to obtain subject opinions of the displays used in relation to the tasks encountered in the flight plan.

#### Conclusions

There were no gross differences in either the level of performance reached or the effort needed to maintain a level of performance between the combined and separate displays. The possibility of small differences between the displays remains. Active flight manoeuvres produced more behavioural and physiological activity than passive ones.

EMERY, J.H. and DOUGHERTY, D.J. *Contact analogue simulator evaluation: Climbout, hover, cruise and descent manoeuvres*. BHC D228-421-017, 1964a.

This study was designed to evaluate the contact analogue vertical display which is an electronically generated encoded representation of the real world capable of presenting sensed information for altitude, airspeed, heading, pitch and roll. Encoded ground position and flight path can also be generated. Pilots performed helicopter manoeuvres which included lift-off, climbout, cruise and approach in the Bell Helicopter Company's dynamic helicopter simulator. The task was designed to envelope different conditions of display content, glideslope angle and heading. Measures of performance included absolute integrated error of climb and approach airspeed, glideslope angle deviation, maximum vertical deviation from glideslope, fore/aft and lateral position error at hover, and vertical speed and altitude at hover. Analysis of the results are presented and discussed. Recommendations for display content for similar manoeuvres in the research helicopter, RH2, are presented.

EMERY, J.H. and DOUGHERTY, D.J. *Contact analogue simulator evaluation: Vertical display with horizontal map display*. BHC D228-421-020, 1964b.

Evaluation was made of the pilot's ability to navigate and to perform simulated helicopter terminal area manoeuvres using contact analogue vertical display symbology alone, and in the presence of the horizontal map display. Combinations of the grid flight pathway and ground position indicator (GPI) on the vertical display with and without the map display were investigated. Performance measures were taken of the terminal area manoeuvres including the landing approach, transition to hover, hover and touchdown. In general, the cruise position of the flight could be accomplished as well when using the basic grid plane on the vertical display in the presence of the map display as when additional symbology (pathway and GPI) was presented on the vertical display. Performance on the approaches and transition to hover scores indicated improved performance when the additional information was provided by the pathway and the GPI. It was concluded that precision of performance could be improved with the pathway and GPI navigation features on the vertical display, but successful accomplishment of terminal area manoeuvres was not entirely dependent upon this information.

EMERY, J.H., KOCH, C.A. and CURTIN, J.G. *Contact analogue simulator evaluation: Investigation of director symbols, display alteration, and the presentation of secondary flight information*. BHC D228-420-008, 1967.

The experimental work was performed in the flight simulation laboratory and made use of a dynamic platform programmed with UH-1 helicopter equations of motion. Three areas of research were investigated. One area included a series of experiments evaluating the use of different types of director symbols in the contact analogue. Another area included a series of experiments to improve performance in basic manoeuvres. A third area studied was the display of secondary flight information with the contact analogue. Experimental results are reported and discussed.

ETO, D.K., STREETER, E. and WEBER, J.W. *Tactical data systems design concepts evaluation*. R & D Report April 1973-March 1974. AFFDL TR-74-53, 1974.

Portions of a flight data management system for a single-seat multiple role fighter-bomber were studied using a simulator. The effects of various combinations of manual or automatic target tracking and manual or automatic aircraft steering on system performance and pilot workload were investigated. Starting from a typical situation of automatic target tracking, manual steering and manual weapon release, the increase in pilot workload and degradation of release point caused by manual target tracking was shown to be considerable. Additionally, an increase was demonstrated in system performance and reduction in pilot workload due to the addition of a flight command function that integrates the weapon delivery calculations with the flight control system.

FRANCIS, B.C. *Display systems for VTO transport aircraft*. IEE Conference Publication No.80, 1971, 301-305.

A V/STOL study carried out on the Hatfield fixed-base simulator is described. The operational requirements of an aircraft flying profiles anywhere between the very shallow angles typical of conventional aircraft up to the limiting case of vertical ascent and descent were investigated. A comparison of the HUD VTOL and STOL studies indicates that properly processed director information need not be intimately related to quantitative information. An assessment of the concept showed that it was possible to provide the pilot of even a very complex aircraft with much of the information in a form that he would require for the performance of an accurate and safe landing.

GAINER, C.A. and OBERMEYER, R.W. *Pilot eye fixations while flying selected manoeuvres using two instrument panels*. Human Factors, 1964, 6, 485-501.

The purpose was to investigate eye fixations as they occurred while pilots "flew" on instruments in two panel configurations. The first panel was equipped with vertical moving-tape instruments. The second was fitted with round-dial instruments. Sixteen very experienced pilots, aged from 28 to 43 years, took part. The study was conducted in a Link MB-5 simulator having the flight characteristics of a high performance jet aircraft. A standard flight plan was used, allowing comparison of both instrument panels across identical representative manoeuvres. System performance measurements were taken during scoring periods and, simultaneously, a film of the pilot's eye movements was made. Thus the data collected allows an analysis of system performance, eye movements, and the correlation of performance and eye movements for each combination of manoeuvres and instrument panels.

GALLAGHER, J.T. and NELSON, W. *Use of simulators in the design and development of flight control systems*. SAE 730933, 1973.

A review of what is currently possible in simulation precedes the main discussion which deals with the application of simulators to the design and development of flight control systems. The Northrop Large Amplitude Simulator with a wide-angle visual system and six-degrees-of-motion-freedom is cited as typical of what can be achieved. This is followed by a description of some validation experiments that lend credibility to the usefulness of simulators. Several examples of the role that they play in flight control design are identified. These range from development of flight control laws through preferred methods of mechanisation, touching on interaction between controllers on separate axes, and conclude with a discussion on pilot-induced oscillations on the lateral axis. In this way it is possible to present a picture of how simulators can be used in the development of flight control systems for advanced fighter planes such as the Northrop YF-17 lightweight fighter.

GEISELHART, R., JARBOE, J.K. and KEMMERLING, P.T. *Investigation of pilot's tracking capability using a roll command display*. ASD TR-71-46, 1971.

#### *Object*

The main purpose was to obtain baseline standard data on the ability of trained pilots to track a command steering display using angle rate information for sensing deviation from a course to the target. A secondary aim was to gather preliminary data on the effect on angle rate tracking of a step function update of target position.

#### *Subjects*

Ten USAF pilots took part.

#### *Equipment*

A F-111-A simulator was used, with pitch, roll and heave motion.

#### *Method*

The mission consisted of flying the simulator at 450 knots and 6,000 feet to a designated target while tracking or keeping the bank steering needle centred. Various segments of the mission were designed to measure pilot tracking ability under perturbed and unperturbed conditions. Twenty-seven different scores were obtained to determine pilot tracking performance.

#### *Conclusions*

1. Tracking performance yielding an average error of less than 0.4 milliradians when steering an aircraft in the lateral direction is attainable by pilots if operational conditions are ideal and proper error information is displayed on the ADI command bar.
2. Pilots are able to adjust satisfactorily to a fairly large target update in steering a simulator, and they can nearly equal the performance of pilots who have an uninterrupted approach to a target.
3. Pilots are able to follow steering commands very well and are probably more limited by system parameters than individual ability to track.
4. All performance measures used in this study are useful in describing tracking performance, with absolute average error being preferred for statistical inference.
5. Sufficiently reliable data on tracking was obtained to establish baseline norms for pilot tracking ability in the lateral direction, based on an ideal system.

#### *Recommendations*

Areas recommended for further research are:-

1. System degradation on angle rate tracking (remove inertial guidance system, etc).
2. Introduction of systems operator using simulation of TV tracker to provide angle rate error information with the pilot having visual reference available.
3. Man-machine trade-off analysis using complete multiloop simulation of two operators - a pilot and systems operator interacting.

GEISELHART, R., KEMMERLING, P., CRONBURG, J.G. and THORBURN, D.E. *A comparison of pilot performance using a centre stick versus sidearm control configuration.* ASD TR-70-39, 1970.

*Aim*

The primary purpose was to compare the performance of a group of pilots using centre stick, dual side stick and single side stick controls during LAHS missions. A secondary purpose was to compare left versus right side stick control. Pilot acceptance of each control was also surveyed.

*Equipment*

An F-111 simulator with pitch, roll and heave motion.

*Subjects*

Six very experienced USAF jet pilots took part. Their average age was 34 years. All had previously used this simulator.

*Method*

Each pilot executed 17 missions using each of the controllers. Each mission lasted 40 minutes. Performance measures during climbout, a terrain-following portion, two banking turns and five ILS approaches were obtained to test the feasibility of side stick control under LAHS conditions. Course steering, airspeed, pitch and ILS deviations were used to compare pilot performance. The results were examined using analysis of variance. In addition, pilots gave their subjective opinions on questionnaire forms. These were assessed using the Cooper Rating Scale.

*Conclusions*

Landing an aircraft using a side stick appears to present no difficulty and is probably as good, if not better, than a centre stick especially for the fine control inputs used in landing. Manoeuvring at altitude also seems relatively easy with a side stick. The pilot opinion data reflected a general acceptance of the side sticks, with average Cooper rating scores close to centre stick ratings. Dual side sticks are better than single sticks in that they allow the pilot the choice of hand for other task accomplishments. Further, a pilot flying with a dual stick can alternately fly with the right and left side stick and thus reduce fatigue effects. Performance data and pilot opinion seem to endorse the overall feasibility of side sticks.

*Recommendations*

Areas for further study are:

- (a) Use of side sticks in missions of longer duration to better assess fatigue effects.
- (b) Use of side sticks in a high turbulence environment, and
- (c) Use of side sticks equipped with an adaptive gain control system.

GERDES, R.M. and WEICK, R.F. *A preliminary piloted simulator and flight study of height control requirements for VTOL aircraft.* NASA TN-1201, 1962.

*Equipment*

A fixed-base simulator, two helicopters and a deflected jet VTOL vehicle.

*Method*

Four NASA research pilots executed a series of simulated vertical upward and downward height changes as rapidly as possible between two established altitudes with a minimum of overshoot. Pilot opinion ratings (Cooper Scale) were used to find the relationships of control sensitivity and control power to damping for both normal flight and augmentation failure conditions. A limited number of flight tests were made to provide data for correlation with simulator results.

*Conclusions*

1. Optimum height control system sensitivity lies between 7 and 12 ft/sec/in.
2. An upward acceleration of 1.2 g was the lowest value of control power necessary for "satisfactory" control characteristics. The level for minimum safe operation was 1.05 g.
3. Control sensitivity and damping as well as control power and damping relationships indicate that vehicles designed to operate within the "satisfactory" limits are assured of operation in at least the "acceptable" region in the event of complete loss of artificial vertical damping.
4. Pilot opinion ratings deteriorate rapidly with increasing control response time constant, particularly when low damping levels exist.
5. Positive ground effect generally improves height control handling qualities, but additional damping is required to cope with the oscillatory hovering behaviour induced at control power levels above 1.2 g.
6. Negative ground effect causes a rapid deterioration in controllability. When combined with low control power, negative ground effect can cause dangerously excessive sink rates.
7. Simulator results correlate well with the limited amount of flight data obtained.

GOLD, T. *Flight simulation study of head-up displays for high-speed flight at low altitudes.* Proceedings of IEEE-GMMS ERS International Symposium 'Man-Machine Systems', Cambridge, England, September 1969.

The author conducted a simulation study to evaluate the relative effectiveness of several HUDs for LAHS flight under automatic and manual control. Flights were made in a B-47E simulator in which a wide-field HUD system was installed. Compatible automatic and flight director control systems were simulated. Control dynamics were the same for both systems so that the flight director could be used to monitor the performance of the automatic flight system. Four test pilots performed a total of 167 runs, under instrument conditions over a simulated rough-terrain range with a nominal clearance of 200 feet.

*Conclusions*

The results indicate that a HUD with a terrain carpet assists the pilot in monitoring the conduct of LAHS missions. This display helps the pilot to recognise both active and passive malfunctions in either the autopilot or the flight

director systems. The terrain carpet and the flight director are the primary display images which make higher levels of performance possible. A control mode indicator provides useful anticipatory information for the pilot with the terrain-following command logic used here.

GRAHAM, W. and MANGULIS, V. *Results of a visual detection simulation experiment for the evaluation of Aircraft Pilot Warning Instruments (APWI)*. Final Report. AD A-017023/3, 1974.

Results of an experiment to evaluate APWI in a Visual Detection Simulator (VDS) are reported. A high correlation between observations in the simulators and the real world was found. APWI systems with sharp range and altitude cut-offs were simulated with bearing resolutions of 180 degrees, 30 degrees and 2 degrees. Part of the experiment was run with no APWI at all for comparison. The results show that the most critical factor in determining the probability of detection of a target is the time available to the pilot for detection. If the time is long enough, the pilot will eventually see it, and if the time is too short, even the best of APWI will not help him. There was significant variation among pilots in their ability to detect targets, and extreme differences were found between the best and the worst pilots in this respect.

HARRIS, R.L. and HEWES, D.E. *An exploratory simulation study of a HUD for general aviation light planes*. NASA TN D-7456, 1973.

The concept of a simplified HUD referred to as a landing-site indicator (LASI) for use in light planes is discussed. Results of a fixed-base study exploring the feasibility of the LASI concept are presented in terms of measurements of pilot performance, control activity parameters and subjective comments of four test subjects. These subjects, all of whom had previous piloting experience in this type of aircraft, performed a series of simulated landings both with and without the LASI, starting from different initial conditions in the final approach leg of the landing manoeuvre.

HASBROOK, A.H. *A comparison of effects of peripheral vision cues on pilot performance during instrument flight in dissimilar aircraft simulators*. FAA AM-68-22, 1968.

The author studied the use of peripheral vision cues for providing bank angle information, and their effect on pilot performance during simulated flight. Two different simulators were used viz:

(a) A Convair 340 simulator representing a medium weight, straight wing aircraft powered by two piston engines and

(b) A B-720 simulator representing a heavy swept-wing transport with four jet engines.

Twenty pilots participated in the B-720 study. Thirty others "flew" the Convair 340, but only data from the most experienced twenty of these was used in the analysis. The peripheral vision cues were provided by two sets of coloured lights on the pilot's control wheel in each simulator. Turns to the left triggered illumination of a left-hand light. Turns to the right illuminated a right-hand light. Flash frequency gave an indication of bank angle. The peripheral lights were used in conjunction with certain instruments on the panel.

#### *Conclusion*

No significant difference was found between pilot performance in the dissimilar type vehicles, suggesting that peripheral vision cues may be equally useful regardless of differences in size, weight and flight characteristics of fixed-wing aircraft.

HASBROOK, A.H. and YOUNG, P.E. *Pilot response to peripheral vision cues during instrument flying tasks*. FAA AM-68-11, 1968a.

#### *Equipment*

A Convair 340 simulator modified to present the flight characteristics of a light twin jet.

#### *Method*

In an attempt to associate more closely the visual aspects of instrument flying with that of contact flight, a study was made of pilot response to peripheral vision cues relating to aircraft roll attitude. Pilots (with flying hours ranging from 52 to 12,000) "flew" flight patterns while data on aircraft bank angle, heading, altitude, peripheral vision cue signals, eye movements and the solution of mathematical problems was recorded during simulated flights involving typical instrument flying manoeuvres.

#### *Findings*

Results suggest that substantial gains can be achieved in instrument flying capability by the use of peripheral vision cues as they relate to provision of continuous bank angle information. The data also indicate such cues may be useful in preventing inadvertent entry into steep banks and subsequent loss of control when turbulence prevents visual interpretation of the attitude indicator.

HASBROOK, A.H. and YOUNG, P.E. *Peripheral vision cues: Their effect on pilot performance during IL approaches and recoveries from unusual attitudes*. FAA AM-68-12, 1968b.

#### *Equipment*

A Boeing 720 simulator with pitch and roll motion was used. The instrument panel was typical of airline aircraft.

#### *Method*

Hasbrook and Young (1968a), using a Convair 340 simulator showed that peripheral vision cues relating to bank angle significantly improved the performance of pilots flying high altitude holding patterns in IFC. In this study

the experimenters explore the effects of similar peripheral vision cues on the performance of 20 transport-rated pilots during simulated instrument landing approaches in a Boeing 720 simulator. Recoveries from unusual attitudes are also investigated.

#### Findings

Results suggest that peripheral vision cues

1. Improve control of bank angle during instrument approaches.
2. May be safely substituted in an emergency for a failed attitude indicator and
3. Result in significantly less time being required for recovery from unusual attitudes. No reversals were observed during recoveries using peripheral vision cues.

#### Reference

Hasbrook, A.H. and Young, P.E. *Pilot response to peripheral vision cues during instrument flying tasks.* FAA AM-68-11, 1968a.

HOPKIN, V.D., POULTER, R.F. and WHITESIDE, T.C.D. *Effects of a blinded retinal area on performance of a simulated flight task.* IAM R-449, 1968.

#### Method

The effect of a blinded retinal area on human performance in the IAM fixed-base simulator was studied in eight pilots from the RAE's Experimental Flying Department. Each pilot familiarised himself with the simulator. Then each "flew" a fixed flight plan lasting about 90 minutes. During this time light flashes of varying size ( $2^\circ$  or  $5^\circ$ ) and retinal position (central or peripheral) were presented at two minute intervals. Each flash was presented only when a manoeuvre had been completed and the pilot was flying straight and level. The flashes were of sufficient intensity to produce an after-image which had no permanent effects but which prevented the pilot from seeing his flight instruments through it for a period of up to a minute. Errors in bank, heading or airspeed were introduced when the flash was presented and the pilot had to correct the errors he noticed.

#### Conclusion

On the whole, flashes of the size and intensity used produced no gross impairment in the pilot's ability to correct errors in bank, airspeed or heading although larger and more intense flashes might do so. Further effects might be produced by dazzle or loss of dark adaptation. The fact that heading was affected most was attributed to the need to read smaller details on the compass than on other flight instruments in order to detect error.

HOWELL, J.D. *Simulator evaluation of pilot assurance derived from an airborne traffic situation display.* FAA EM-72-3, 1972.

#### Equipment

A display-equipped cockpit simulator corresponding to the B707-123B jet transport.

#### Method

A series of simulator tests were carried out to estimate the pilot assurance value of airborne displays used as traffic situation monitors in high-density terminal area airspace. Twenty professional pilots were exposed to a set of normal and abnormal terminal approach situations. Their level of assurance was found from their detailed knowledge of each situation, measured by stop-action quizzes and their ability to detect conflicts. Workload or the degree of difficulty the pilots experienced in acquiring relevant information about the situation was also regarded as a component of assurance. Specific problem areas emphasised in the tests were simultaneous approaches to providing a "picture" for the pilot when discrete address data links replace current ATC voice party-line communications.

#### Conclusions

Pilot assurance was found to increase markedly when a traffic situation display was available. The display more than compensated for the loss of party-line information when the discrete address command mode was in effect. The acquisition and retention of information also became much more selective with the display, focussing on such critical items as the relative position of nearby aircraft. The detection of malfunctions and blunders improved greatly, although single pilots simultaneously performing the inner loop tasks of flying the aircraft, spacing themselves precisely in trail, and tracking the ILS beam did not detect all the conflicts. Most of the pilots felt that the overall cockpit workload, with the display added to existing instrumentation, was acceptable.

HUDDLESTON, H.F. *HUD evaluation by limited flight simulation. Phase 2: Comparison of two targets, four markers and four director tracks.* IAM R-285, 1964a.

#### Aim

This is the second in a series of experiments performed to evaluate the relative merits of small alterations in symbol shape or size as part of a HUD programme. The symbols to be evaluated in this study were:-

Markers:	0.5° diameter, 1.0° overall (small wings)
	0.5° diameter, 1.5° overall (medium wings)
	0.5° diameter, 2.0° overall (large wings)
	0.75° diameter, 1.5° overall (large diameter)
Targets:	0.25° diameter circle
	cross, 0.5° or 0.75° overall to fit marker
Director tracks:	4 track lines
	3 track lines
	3 track lines, with central gap
	3 track lines, ladder

*Subjects*

Eight RAF Bomber Command pilots took part. All were unfamiliar with a collimated projected display.

*Equipment*

A single-seat fixed-base cockpit containing a HUD, control column, throttle, rudder pedals, an intercom system and no conventional instruments was linked to a computer capable of presenting a pilot with a predetermined flight task. Variations in HUD symbol design were by push-button selection of pre-planned circuits.

*Method*

Each pilot flew a total of thirty-two 15-minute simulated sorties to a pre-determined flight plan. During these flights, all the thirty-two possible symbol combinations were displayed. No two pilots met the same displays in the same order. Debriefing questionnaires and certain flight measurements were used as assessment criteria.

*Conclusion*

Thirty-two display variants were found to be equally satisfactorily flyable. The inter-subject variation was large. More fruitful areas for future research are suggested.

*NOTE:*

Refer to Huddleston, H.F. and Samuel, G.D. IAM Report 261, 1963, and Huddleston, H.F. IAM Report 304, 1964b.

HUDDLESTON, H.F. *Head-up display evaluation by limited flight simulation. Phase 3: Three range scales and the director track.* IAM R-304, 1964b.

*Aim*

This investigation is the third in a series concerned with a simulator evaluation of various director symbols with a view to assembling the best possible display (in terms of general flight performance and pilot opinion) based on a design developed in the UK since 1953. The specific comparisons included in this study were:—

A circular range scale (6.3° long) with quadrature marks.

A horizontal range scale (4.0° long) with quadrature marks.

A vertical range scale (4.0° long) with quadrature marks.

A director track of 4 logarithmically spaced perspective lines.

No director track at all.

*Equipment*

This consisted of a single-seat static cockpit containing HUD equipment, ejection seat, conventional stick, throttle and rudder controls, and an intercom system. Conventional instruments and associated gear were not included.

*Subjects*

Eight pilots from the RNAS at Yeovilton took part.

*Method*

Each pilot simulated a series of attack profiles during which every possible range scale and director track was displayed. Pilot opinion questionnaires and certain flight performance measures were used to determine the effectiveness of the displays.

*Conclusions*

Equally good performance was achieved using any of the three range scales but a circular scale is considered to have some advantages over either a horizontal or a vertical rectilinear one. The director track generally led to improved flight path accuracy for most pilots in most flight stages, presumably by emphasising the motion relationships which exist between the two elements of the central tracking task. However, the track impaired performance of the low-altitude bombing system attack manoeuvre, probably by cluttering the display. More research is needed to investigate the presumably limited value of this component.

*NOTE:*

Refer to Huddleston, H.F. and Samuel, G.D. IAM Report 261, 1963, and Huddleston, H.F. IAM Report 285, 1964a.

HUDDLESTON, H.F. and SAMUEL, G.D. *HUD evaluation by limited flight simulation. Phase 1: Comparison of two targets and two aircraft marker symbols.* IAM R-261, 1963.

*Aim*

Starting with a general HUD symbol design known as the Spectocom or Rank-Cintel display, this series of investigations set out to evaluate the merits of fairly small alterations in symbol shape or size as part of a wider programme of HUD assessment. The relative merits of two targets (a spot and a larger circle) and two markers (a circle and a circle with wings) were evaluated in this study. As used in this HUD, the targets represented demanded position and the markers, actual position.

*Equipment*

A simple static cockpit containing a control column, throttle, rudder pedals, intercom and no conventional instruments, was used. An external earth-horizon-sky representation was projected in front of the cockpit.

*Method*

Eight RNAS pilots flew a total of 19½ simulator hours, according to a balanced design, and answered a total of 40 questionnaires. Four USN test pilots provided incomplete data amounting to 7½ hours and 12 questionnaires.

*Conclusions*

Performance measures demonstrated that pilots were capable of flying almost equally well using any one of the four possible combinations of two targets and two markers, although the larger target (small circle) with a winged marker led to generally better flight path accuracy in most flight modes. Preferences tended to confirm these findings. A few comments are included on the general methodology of measuring pilot performance and opinion

on the HUD design concept, and on simulators as human factors research tools.

NOTE:

Refer to Huddleston, H.F. IAM Reports 285, 1964a, and 304, 1964b.

HUDDLESTON, H.F. and WILSON, R.V. *An evaluation of the usefulness of four secondary tasks in assessing the effect of a lag in simulated aircraft dynamics.* Ergonomics, 1971, 14, 371-380.

Eight non-pilots were required to perform a tracking task using an electronic wind-shield display. The task had two levels of difficulty — an unlagged condition and a more difficult condition having an exponential lag of 0.5 secs. Integrated tracking error scores alone showed no distinction between the two levels of difficulty. Four secondary tasks were, in turn, added. These involved a response to digits sighted in the subject's forward field of view. The secondary tasks were of comparable difficulty as shown in pre-tests using the above eight subjects. Two secondary tasks indicated a difference between the primary task conditions. The addition of a secondary task also permitted tracking error scores themselves to indicate a difference.

INCE, F., WILLIGES, R.C. and ROSCOE, S.N. *Aircraft simulator motion and the order of merit of flight attitude and steering guidance displays.* Human Factors, 1975, 17, 388-400.

Non-pilots were tested in various simulated flight tasks to provide information concerning both the frequency-separated display principle and the effects of simulated motion cues. The frequency-separated display led to reductions in disturbed attitude tracking errors, in the incidence of control reversals, and in recovery times to level flight from unknown attitudes. Two modes of motion (steady bank angle and constant roll) were tested and both facilitated disturbed attitude tracking performance, but inappropriate acceleration forces created by sustained banking motion interfered with command flight path tracking. Washout motion (constant roll) gave results most closely akin to flight data. It was noted that motion systems which introduce gravitational cues not present in flight can be as damaging to the validity of an experiment as the complete absence of acceleration cues.

JACOBS, R.S., WILLIGES, R.C. and ROSCOE, S.N. *Simulator motion as a factor in flight director display evaluation.* Human Factors, 1973, 15, 569-582.

#### *Aim*

To compare eight flight director displays exhibited to pilots on a CRT in a simulator.

#### *Equipment*

A GAT-2 simulator. This device has cockpit controls, flight response and instrumentation similar to those of a light twin-engine aircraft. It was run fixed-base in the present study.

#### *Subjects*

Eight pilots, each holding a Private Pilot Certificate, took part. All were college students who had received their flight training at Illinois University Institute of Aviation. Their flight experience ranged from 40 to 150 hours.

#### *Method*

Eight flight director displays that encompassed the combinations of four attitude presentations (moving horizon, moving airplane, kinalogue and frequency-separated) and two modes of command presentation (pursuit and compensatory) were compared in a static GAT-2 trainer. The Johnson et al. (1971) data from an identical experiment, but with motion, was combined with the replicated data of this study. The combined data analysis was conducted on the azimuth steering error performance.

#### *Results*

Performance was affected by both the motion cues and the interaction between command steering presentation (pursuit or compensatory) and attitude presentation (moving horizon, moving airplane, kinalogue or frequency-separated). In addition, there was an interaction among command steering presentation, attitude presentation, and the presence or absence of simulator motion.

#### *Conclusions*

The results of research conducted in ground simulators must be interpreted with care in view of the potential effect of differences between the simulated and flight environments. Significantly different results occurred as a function of the presence or absence of simulator motion. Implications of these results raise doubt about the validity of findings from simulator experiments in which whole-body acceleration cues might be a factor.

Johnson, S.L., Williges, R.C. and Roscoe, S.N. *A new approach to motion relations for flight director displays.* Report ARL-71-20, 1971.

JOHNSON, S.L., WILLIGES, R.C. and ROSCOE, S.N. *A new approach to motion relations for flight director displays.* ARL 71-20, 1971.

#### *Subjects*

Eight pilots, each holding a Private Pilot Certificate, acted as subjects. All were University of Illinois students and their experience ranged from 40 to 150 hours solo.

#### *Method*

Two new approaches to the problem of preferred motion relationships for attitude displays were explored (1) a time-lagged frequency-separated kinalogue display and (2) a hybrid frequency-separated presentation employing aileron position to quicken the indication of bank attitude changes. Eight flight director display configurations that encompassed the combinations for four attitude presentations (moving horizon, moving airplane, kinalogue

and frequency-separated) and two modes of command presentation (pursuit and compensatory) were compared in a Link GAT-2 flight trainer, which was run moving-base for this study.

#### Conclusions

Overall, the moving airplane presentation was superior to the moving horizon, and the pursuit configurations were better than the compensatory configurations. Command presentation interacted with attitude presentation, the pursuit moving airplane combination being disproportionately superior to all others. The results are discussed with reference to previous and future research.

KARIM, B., BERGEY, K.H., CHANDLER, R.F., HASBROOK, A.H., PURSWELL, J.L. and SNOW, C.C. *A preliminary study of maximal control force capability of female pilots*. FAA AM-72-27, 1972.

Using a cockpit mock-up adapted for strength tests, a study was made of the maximal voluntary forces a representative sample of 25 female pilots could exert on each flight control. The percentage of maximal strength versus endurance relationship was established and compared with the results of other investigators. The results indicate a need for further study both in simulated and actual flight.

KELLEY, C.R., de GROOT, S. and BOWEN, H.M. *Relative motion II: Some relative motion problems in aviation*. NTDC 316-2, January 1961.

To explore relative motion problems in a variety of pilot and navigator tasks, both field and laboratory studies were conducted. In the former, methods used by pilots to fly intercepts were surveyed, the guidance of air-to-ground missiles was analysed, and relative motion problems in attitude and navigation displays (including ANIP display) were identified. Two experiments were carried out to determine "natural" responses to "inside-out" displays as a function of display size and to determine how to eliminate wrong responses to roll information presented in such displays (reversal errors). The study confirmed the superiority of "outside-in" displays, made specific recommendations for the design of navigation and attitude displays for air and spacecraft and suggested ways of eliminating reversal errors. It also recommended procedures for missile guidance and provided insights into the cues used by pilots in visual intercepts.

KREIFELDT, J.G. and WEMPE, T. *Pilot performance during a simulated standard instrument procedure turn with and without a predictor display*. Proceedings of 9th Annual Manual Control Conference, Massachusetts Institute of Technology, Massachusetts, U.S.A., 1973, 147-162.

This simulator study was conducted to measure the effectiveness of predictor information of a computer-simulated aircraft's horizontal and vertical position displayed on a CRT. Professional pilots executed standard instrument procedure turns at constant height in constant cross-winds with and without their predicted ground track displayed.

#### Conclusion

The results show that the display with the predicted ground track was significantly superior to the display without this information and that the subjects were generally satisfied with this type of information. Mean RMS lateral path error was independent of the cross-wind velocity with the predictor information and increased without it with increasing wind velocity. RMS stick activity decreased with the predictor display which also uncoupled aileron and elevator activity.

LAYTON, D.M. *A simulator evaluation of pilot performance and acceptance of an aircraft rigid cockpit control system*. Naval Postgraduate School, Monterey, California, U.S.A. Paper 57 LN 70071A, 1970.

A two-axis compensatory tracking task with a randomly appearing signal displayed in a fixed-base simulator was used to evaluate the performance of 105 pilot and non-pilot subjects using four separate control sticks – two movable and two rigid. Pilot acceptance of the rigid cockpit controllers was determined by comparing individual pilot ratings of the sticks. In general, in both performance and opinion, the rigid systems were found to be superior to their movable counterparts. Steps were taken to avoid errors due to pilot bias, learning, fatigue or adaptation. The results obtained are subject to several test limitations including the low stick-force levels used, the lack of aircraft vibration effects and the realism of the simulation.

LEEPER, R.C., HASBROOK, H.A. and PURSWELL, J.L. *Study of control force limits for female pilots*. FAA AM-73-23, 1973.

#### Equipment

A fixed-base Convair-340 simulator, representing a twin-engine forty-passenger plane, was used. No outside visual cues were provided. Tensions on the controls were varied using a pulley and weight system.

#### Subjects

Twenty-four pilots were chosen as representative of the population of women pilots in age, height and weight.

#### Method

Each subject performed tracking tasks on two instruments – the attitude indicator and the turn and bank indicator – at three levels of control tension. The variables measured were "errors" in pitch angle, bank angle and rate of turn. During any one trial the subject tracked on two of these variables while the third remained fixed in the null position.

The subject's task was to apply enough force to keep the two active displays as close to centre as possible.

#### Conclusion

The data show that the current FAR 23.143 control force limits for general aviation aircraft are too high for a majority of US female pilots. Data on strength capabilities of women for operating aircraft controls are presented in the form of prediction equations for level of control force versus time.

LEMONS, J.L. and DUKES, T.A. *A simulator study on information requirements for precision hovering*. NASA TM-X-62464, 1975.

The authors report on a fixed-base simulator study of an advanced helicopter instrument display using translational acceleration, velocity and position information. The simulation involved piloting a heavy helicopter using an Integrated Trajectory Error Display in a precision hover task. Two basic areas were studied. The effect on hover accuracy of adding acceleration information was of primary concern. Also of interest was the pilot's ability to use degraded information derived from less sophisticated sources. The addition of translational acceleration to a display containing velocity and position information did not help the pilot to improve his hover performance significantly but it did seem to increase the damping of the man-machine system. The pilot's performance did not significantly suffer when he used degraded information, obtained by deriving approximate velocities from attitude and position components.

LLOYD, D.A., LEGG, R.C.F. and WILLIAMS, E.M. *MOD flight simulator at Smiths Industries Ltd. Task 5. Assessment of the effects of height resolution in a head-up display*. Smiths Industries Ltd, Aviation Division, Bishops Cleeve, Cheltenham, England. Report RID 1302, November 1971.

#### Summary

The authors describe a simulator exercise carried out to determine the effects of the magnitude of the resolution of the indicated height in a HUD on the ease and accuracy of the longitudinal control of an aeroplane.

#### Conclusions

The results indicate that a resolution of 10 feet tends to give slightly better results for height holding accuracy than a resolution of 50 feet, except under difficult conditions when there is little obvious difference between the performance with the two resolutions. The lack of rate information with the 50 feet resolution and the apparent higher workload with the 10 feet resolution combined with the slightly improved accuracy with the 10 feet case, indicate that the choice of 50 feet resolution above 10,000 feet and 20 feet resolution below this altitude for the Jaguar HUD was a good decision.

MATHENY, W.G., DOUGHERTY, D.J. and WILLIS, J.M. *Relative motion of elements in instrument displays*. Aerospace Medicine, 1963, 34, 1041-1046.

An experiment compared pilots' attitude appreciation, especially in roll, in a dynamic or static simulator cockpit and a rolling or hovering helicopter. Cockpit motion was found to lead to quicker and more accurate decisions about attitude changes than display motion alone. An instrument (an outside-in horizon) judged acceptable in a static situation may be unacceptable in a realistically dynamic one.

MATHENY, W.G., WILLIAMS, A.C., DOUGHERTY, D. and HASLER, S.G. *The effect of varying control forces in the P-1 trainer upon transfer of training to the T-6 aircraft*. HumRRO 53-31, 1953.

The authors attempted to find whether subsequent performance in learning climb and glide manoeuvres in a T-6 aircraft was affected by differential amount of control-stick pressure used during previous training in a P-1 Link trainer. Three groups of subjects were given training in climbs and glides in the T-6 aircraft. Two of these groups were given training in these manoeuvres in the Link P-1 prior to their training in these manoeuvres in the T-6. One of these two "simulator" groups learned the manoeuvres in the P-1 with the elevator control force adjusted to correspond with that of the T-6 aircraft. The other "simulator" group learned the manoeuvre in the P-1 with the elevator control force adjusted to a minimum. The third group, a control group, learned the manoeuvre only in the T-6 aircraft. Performance in the T-6 was assessed by the number of trials required during T-6 training to achieve a specified standard of performance. It was found that the groups given simulator training achieved criterion performance in the glide manoeuvre in a significantly fewer number of trials than the control group. Performance of the simulator groups in the climb manoeuvre was superior to that of the control group, but the differences were not significant between simulator groups.

McGUINNESS, J., DRENNEN, T.G. and CURTIN, J.G. *Manual control in target tracking tasks as a function of controller characteristics: A flight simulator investigation. Phase 2*. McDonnell-Douglas Corporation, Douglas Aircraft Co., 3855 Lakewood Blvd., Long Beach, California 90801, U.S.A. MDC E-1148, 1974.

An examination was conducted of finger-tip controllers integrated into aircraft throttles and used in target acquisition and tracking tasks. The experimental variables included two types of controllers (force and displacement) and two types of output function (linear and step) under three levels of gain and three levels of target speed. In the evaluation, sixteen pilots performed an aircraft control task in addition to a target tracking task in a fixed-base simulator. Absolute pitch and roll deviations were obtained to measure aircraft control error. Measures of target tracking task performance included target acquisition time and error, time on target, X and Y axis tracking error, overshoots and control reversals. The results showed that the force controller, in combination with a step

function, was associated with a significant increase in acquisition and tracking proficiency when compared to other controller/output function combinations.

MELANSON, D. *Simulator evaluation of pilot assurance derived from an Airborne Traffic Situation Display (ATSD). Phase 2: Traffic awareness improvement. Final Project Report. 1 March 1972-30 June 1973. FAA EM-74-10, 1974.*

Using a fixed-base B-707 simulator, forty-four professional pilots took part in a number of simulator experiments designed to measure pilot awareness, using party-line voice communications and a possible future system employing the ATSD. Tests were made with and without an in-trail spacing task and with one and two-man flight crews. In addition, a pilot's ability to detect and react to conflict situations was measured during both single and parallel runway operations. The effects of conflict alarms and the frequency of updating information were also examined.

#### *Conclusions*

The ATSD was found to be superior to the party-line communication channel as a source of traffic awareness. With no spacing task, the detection of conflicts prior to the point of closest approach occurred in all cases using the ATSD, regardless of whether an alarm was used or whether a crew or single pilot was being tested. With a spacing task, a high percentage of conflicts was detected by single pilots, but not always in time to take safe evasive action, particularly during closely-spaced parallel approach. TAU (range divided by range rate) alarms reduce the reaction time in both crews and single pilots in responding to conflicts in some, but not all, conflicts.

MENGELKOCH, R.F. *Pilot simulator performance with two flight instrument panels. The Martin Company, Baltimore, Maryland, U.S.A. ER-10846, 1961.*

#### *Method*

A standardised flight plan was flown by thirty USAF jet-qualified pilots in a YF-102 Link simulator using two instrument panel configurations. With common altitude and heading indicators, one panel used circular scale instruments for mach, airspeed, vertical rates and altitude, while the other panel had vertical scale instruments for the same parameters. Pilot performance on heading, altitude, mach, vertical rate and airspeed control was measured by electronic scoring equipment in terms of a R.M.S. "error" score.

#### *Conclusions*

It was found that:

1. Heading performance and altitude performance were superior on the panel containing the circular scale instruments.
  2. Mach performance was superior on the panel containing the vertical scale instruments.
  3. Vertical rate and airspeed performance showed no difference between instrument panel configuration.
- Separate analyses for those subjects with and without previous vertical instrument experience did not alter these findings.

MOEN, G.C. and YENNI, K.R. *Simulation and flight studies of an approach profile indicator for VTOL aircraft. NASA TN-D-8051, 1975.*

Simulation and flight studies were conducted using a method of providing supplementary information to the pilot, in conjunction with a CCTV display, during a VTOL instrument approach including deceleration and hover. The supplementary information included range, cross range, ground speed, altitude and rate of climb error, and was displayed on an approach profile indicator. The display was arranged to provide both quasi-command and situation information. Pilots reported that the approach profile indicator display, in conjunction with the CCTV display, resulted in a decrease in workload and an increase in confidence. Also, the results indicated that the approach profile repeatability was significantly improved because of the ground speed and altitude information provided on the indicator.

MONTEITH, W. and LEGG, R.C.F. *MOD flight simulator at Smiths Industries Ltd. Task 4. An investigation of some aspects of an integrated vertical situation display, including the factors affecting the choice of the roll resolving point and the importance of including an indication of sideslip on the display. Smiths Industries Ltd., Aviation Division, Bishops Cleeve, Cheltenham, England. Report RID 1301, December 1971.*

#### *Equipment*

Two aircraft types were selected for the simulator tests - a typical strike aircraft and a SST. The aerodynamic derivatives, flight conditions and the equations of motion have been quoted.

#### *Summary*

A vertical situation display has often been suggested in which three symbols are used to present, on a HUD, an aircraft's pitch attitude, velocity vector and the artificial horizon. These three symbols comprise a truly integrated display in that the aircraft attitude, climb/dive angle and angle of attack are all apparent in a self-evident way. It has further been suggested that such a display can be mechanised simply by adding a symbol, driven by angle of attack, to an existing artificial horizon. These aspects, the choice of roll resolving point, and the importance of including a sideslip indicator on the display, have been investigated. All the runs were done in zero wind conditions.

MURPHY, M.R. and GREIF, R.K. *Simulation evaluation of a perspective clipped-pole display and a thrust-vector controller for VTOL zero-zero landings. NASA TM-X-62464, 1975.*

Five pilots took part in a simulator study to evaluate design features of a perspective clipped-pole display and a side-arm thrust-vector controller for potential application to VTOL zero visibility landings. Analysis of the results, using Student's *t* tests for related means, showed significant learning effects but did not show significant performance differences among display conditions. A mean longitudinal TD velocity of less than 4 knots, a mean vertical

TD velocity of less than 1.22 m/sec and a mean longitudinal position error of 15.24 metres were attained during the final ten trials of the experiment. The conclusion that adequate airspeed and altitude cues could be obtained from the glideslope and runway poles is supported by the absence of significant performance differences among the display conditions.

OLDFIELD, D.E. and HORNER, R.M. *A simulator assessment of three height presentations on a HUD*. RAE TM-Avionics-122, 1972.

Sixteen pilots took part in a fixed-base simulator assessment of three methods of presenting height as the first phase of a larger programme on HUDs. One presentation was a simple numerical read-out as currently used on the Harrier and Jaguar, another was a thermometer presentation based on the American A-7 HUD format, and the third was a numerical presentation supplemented by a representation of an edge-viewed rotating drum. No consistent opinion was expressed by the subjects as to which display was best, but several important comments were made. Quantitative data failed to show any performance difference in height control for one group of subjects without previous HUD experience, but a second group with Harrier or Jaguar experience performed better on the numerical read-out.

ONKEN, R., ADAM, V. and DIERKE, R. *The use of a flight simulator in the synthesis and evaluation of new command control concepts*. Proceedings of AGARD FMP/GCP Symposium 'Flight Simulation/Guidance Systems Simulation', The Hague, Netherlands, October 1975.

A simulator with pitch, heave, roll and sway motion was used for comparative studies of flight path command control systems (FPCC). The first phase was confined to solutions for longitudinal motion. The computational capabilities of the simulator and its motion system were combined to design an automatic controller as well as for the comparison of a number of configurations which differed in both pilot command variables and control loop structure. The comparison of different FPCC configurations was carried out by tracking a curved steep approach path. Both statistical test data and the pilot's comments demonstrate good results for the pilot command parameters – flight path angle derivative or blended flight path angle/flight path angle derivative – with the pilot flight director loop decoupled from that of the automatic flight path control.

PANGBURN, R.C., METZLER, T.R. and KLINE, J.M. *Pilot performance as a function of three types of altitude displays*. FAA RD-72-130, 1972.

#### *Purpose*

To compare three types of altimeter (1) a counter-drum pointer – AAU 19, (2) a 3-inch tape altimeter and (3) a straight digital altimeter.

#### *Apparatus*

A C-135B cockpit with pitch, roll and heave motion was used. The equipment provides total mission simulation. For this experiment, the visual system was not used.

#### *Method*

Thirty-six representative USAF pilots took part, and each flew four simulated flights. Pilot performance measures were taken on eighteen parameters and subjective data was collected on pilot questionnaires. Performance was assessed using analysis of variance.

#### *Conclusions*

All three altimeters appear to be acceptable from a pilot performance standpoint. The digital altimeter is superior to both the tape and the AAU 19 indicators, especially under moderately high task-loaded conditions where precise cross-checks are required. However, the use of such an instrument for rapid ascents or descents has yet to be proven. The AAU 19 was the least readable of the instruments, and during certain altitude transitions, pilots could make 1000-feet reading errors.

PETIT, J.P. and RAYNAL, J.C. *Etude au simulator du pilotage d'un avion STOL en approach*. Proceedings of AGARD FMP/GCP Symposium 'Flight Simulation/Guidance Systems Simulation', The Hague, Netherlands, October 1975. (In French).

The simulator used had pitch, roll and heave motion. This study was conducted to find out the comparative effectiveness of IFR, VFR and velocity vector HUD instrumentation during experiments on the longitudinal handling qualities of a STOL transport in the approach and landing stages of simulated flight. Variant types of STOL behaviour were obtained by altering the engine thrust static and dynamic characteristics and by modifying the lift coefficients so as to give differing flight path margins and flight path rates of change.

QUEIJO, M.J. and RILEY, D.R. *Fixed-base simulator study of the effect of time delays in visual cues on pilot tracking performance.* NASA TN-D-8001, 1975.

Factors which determine the amount of time delay acceptable in the visual feedback loop were examined using a fixed-base simulator. Acceptable time delays are defined as delays which significantly affect neither the results nor the manner in which the subject flies the simulator. The pilot tracked a target aircraft as it oscillated sinusoidally in a vertical plane only. The pursuing aircraft was permitted five degrees of motion freedom. Time delays varying from 0.047 to 0.297 secs were inserted in the visual feedback loop. A secondary task was used to keep the workload constant and to ensure that the pilot was kept fully occupied. Tracking results were obtained for seventeen aircraft configurations, each having different longitudinal short-period characteristics. Results show a positive correlation between improved handling qualities and a longer acceptable time delay.

RICH, P.M., CROOK, W.G., SULZER, R.L. and HILL, P.R. *Reaction of pilots to warning systems for visual collision avoidance.* SAE 720312, 1972.

The authors describe six simulator experiments applied to the development of pilot warning indicators (PWIs). The indicators consisted either of a buzzer or a sectorized visual display. The experiments were concerned with:

- EXPT 1 – the effect of warning rate on pilot performance.
- EXPT 2 – pilot response to imminent collision threats.
- EXPT 3 – the evaluation of scanning patterns.
- EXPT 4 – the value of warning only (i.e. without sectorized information).
- EXPT 5 – the effect of relative motion on pilot performance.
- EXPT 6 – the effect of PWI display on sector size.

Twelve pilots participated in each experiment. They "flew" a Cessna 151 simulator in EXPT 1, a Cherokee cockpit in EXPT 2 and a Link GAT-2 trainer in EXPTS 3–6. The warning indications were given during the course of "flights".

#### Conclusions

1. False alarms and failures to alarm do not destroy the potential usefulness of a PWI, since the detection scores of pilots given twice the number of both alarms significantly exceeded the detection scores of pilots given no alarms at all.
2. Since no standard or instinctive manoeuvre choice was shown by pilots confronted by particular imminent collision threats and, since pilot reaction time averages over two seconds, development of a collision avoidance traffic rule, based possibly on left-seat view considerations, is indicated.
3. Standard scanning geometries do not improve overall detection, but among those tested, the horizontal sweep in ascending height was best.
4. Warning only PWI greatly reduced the undetected nearby target proportion, indicating that a minimum PWI (i.e. without sectorized information) may be of significant value.
5. Since a 15-second search and detection period resulted in mostly correct pilot judgements of target movement, it appears that a PWI with a relatively short range may be of significant value.
6. Using a practical panel indicator, there is nothing to be gained from reducing the warning sector size to less than 30° azimuth.

#### NOTE:

This treatise contains an appendix setting out the minimum requirements for a GAT-2 visual simulation system.

ROSCOE, S.N., DENNEY, D.C. and JOHNSON, S.L. *The frequency-separated display principle: Phase III.* ARL 71-15, 1971.

The authors report on experiments carried out for the US Navy using a GAT-1 instrument trainer with simple motion and turbulence effects. They examine novel methods of presenting information on flight instruments and they compare various types of symbology, presented on a CRT, with the standard Collins 109 Flight System. In an artificial horizon presentation for instance, the symbol of the aircraft is tilted and compared with the normal method of tilting the horizon. Motion and fixed-base presentations are compared. Similar experiments are to be undertaken in a Beechcraft plane.

ROSCOE, S.N. and KRAUS, E.F. *Pilotage error and residual attention – the evaluation of a performance control system in airborne area navigation.* Navigation, 1973, 20, 267-279.

In 1969, by specifically including "pilotage error" in the error budget for area navigation system certification, the FAA legally attached economic premiums and penalties to human, as well as equipment, performance in man-machine system design. Variable errors contributed by pilots tend to be relatively large as compared with the inaccuracies of modern airborne electronic equipment. If a manufacturer believes that his system will yield pilot errors smaller than the generally conservative values assumed by the FAA, the maker is obliged to provide acceptable evidence in support of his contention that his system assures improved pilot performance. To establish the accuracy and freedom from pilot errors associated with systems using various configurations of displays and controls requires both simulator and flight experimentation. The authors carried out an experiment using a GAT-2 trainer in which an automatically adaptive cockpit side task provided a saturating level of pilot workload and allowed the measurement of a pilot's residual attention as a common metric for area navigation system assessment.

SAGER, D. *Simulator evaluation of manually-flown curved Microwave Landing System approaches*. Proceedings of IEEE International Conference 'Systems, Man and Cybernetics', Dallas, Texas, U.S.A., October 1974.

Pilot performance in flying horizontally-curved instrument approaches was analysed by having nine subjects fly curved approaches in a fixed-base simulator using a Microwave Landing System for guidance. Neither the flight director nor the autopilot were used. Evaluations of the system were based on deviation measurements made at a number of points along the curved approach path, and on pilot opinion as expressed in questionnaires.

#### Conclusions

1. Pilots can fly curved approaches, though less accurately than straight-in ones.
2. A moderate wind does not seriously affect curve-flying performance.
3. There is no major performance difference between 60° and 90° turns.

SILVERTHORN, J.T. and SWAIM, R.L. *Manual control displays for a four-dimensional landing approach*. NASA TM-X-62464, 1975.

Six IR pilots flew a STOL fixed-base simulator to study the effectiveness of three displays for a four-dimensional approach. The displays examined were (a) a digital readout of forward position error (b) a digital speed command and (c) an analogue display showing forward position error and error prediction. A flight director was used in all conditions. All the test runs were for a typical four-dimensional approach in moderate turbulence that involved a change in commanded ground speed, a change in flight path angle and two standard rate sixty-degree turns. Use of the digital forward position error display resulted in large overshoot in the forward position error. Some type of lead (rate or prediction information) was shown to be needed. The best overall performance was obtained using the speed command display. It was demonstrated that curved approaches can be flown with relative ease.

SMITH, R.L., PENCE, G.G., QUEEN, J.E. and WULFECK, J.W. *Effect of a predictor instrument on learning to land a simulated jet trainer*. AFOSR 74-1731TR, 1974.

Use of a predictor display has been shown to reduce the difficulty of complex, manual-control pursuit tracking tasks to the level of simple control. The purpose of this study was to explore adaptive use of a predictor display to promote rapid and accurate learning on conventional tracking tasks, i.e. transfer of training.

SOLIDAY, S.M. *Navigation in terrain-following flight*. Human Factors, 1970, 12, 425-433.

The author investigated the problem of navigation in low-altitude high-speed flight. He used the North American Rockwell Corporation (Columbus, Ohio) simulator which provides pitch, roll, heave and sway motion and an outside world TV presentation in pitch and azimuth. Twelve experienced jet pilots "flew" forty-eight 90-minute missions using several combinations of navigational and terrain-following displays in two aerodynamically different types of aircraft. The results showed that the pilots navigated better when they had information from a simulated inertial guidance system than when they did not have this assistance. They navigated better in mountainous terrain when they used a HUD for terrain-following than with conventional instruments and they navigated better in the simulated aircraft with the more desirable handling qualities.

SOLIDAY, S.M. and MILLIGAN, J.R. *Terrain-following with a head-up display*. Human Factors, 1968, 10, 117-126.

A HUD was evaluated in simulated (LAHS) terrain-following flight using a four degree-of-freedom (in roll, pitch, heave and sway) motion simulator. The aircraft simulated was the RF-4C. Six USAF pilots made a total of 108 half-hour "flights" in various terrain, airspeed and visibility conditions. The pilot's task during the flights was to maintain a given clearance altitude and heading at all times.

#### Conclusions

The results showed that terrain-following with the HUD was better than it was with typical in-cockpit instruments. The pilots preferred the HUD to the in-cockpit instruments although they felt that numerous improvements could be made to the HUD used in this test. General findings were that terrain-following efficiency varied with the type of terrain, airspeed and visibility encountered.

SPANGLER, R.M. and SULZER, R.L. *Flight simulation study of air-to-air ranging displays for separation assurance*. FAA NA-68-13 (RD-66-83), 1966.

#### Purpose

To assess the operational value for separation assurance of cockpit display of:

- (a) Warning that another aircraft has intruded within 60 miles, plus constant display of intruder range.
- (b) The same warning and present range plus pilot-to-pilot communications, and
- (c) The warning and present range plus relative bearing of the intruder with communications.

#### Equipment

Curtis-Wright P-2 and P-3 motion cockpits were coupled to a common course-plotting board. The P-2 and P-3 simulators have single cockpits equipped with standard controls, flight instruments and navigation aids. For this project their performance capabilities were altered to approximate those of a typical four-engine jet now operating in the North Atlantic, and the display dials were re-numbered appropriately.

#### Method

Ten pilots "flew" each of nine potential collision courses at a constant height of 30,000 feet, viewing each of the three displays in random order. The problem was to maintain or retrieve a preset course while keeping an intruder aircraft at a 60 mile separation distance. Quantitative data on separation assurance performance (e.g. reaction time, course deviation, and proximity measurements) were collected for each display. The results were examined using analysis of variance.

### Conclusions

Based on the results of 270 runs in a simulated over-ocean situation, it was found that:

1. Range intrusion warning plus constant display of air-to-air range is adequate to ensure maintenance of separation when one aircraft is approaching another at a slow closure rate from the stern or within the rear quarter.
2. Range and warning, supplemented with pilot-to-pilot communications, is not adequate to maintain three-quarters or more of the initial separation when the aircraft are closing rapidly in head-on or ahead-of-the-beam approaches.
3. Provision of relative bearing information does not yield marked enhancement of performance in the head-on situation when employing lateral manoeuvres.
4. All three added displays were adequate for overtaking intrusions with no one method better than the others.

VANDERKOLK, R.J. and ROSCOE, S.N. *Simulator tests of pilotage error in area navigation with vertical guidance - effects of descent angle and display scale*. Human Factors Society, 17th Annual Meeting, Washington DC, U.S.A., October 1973.

Pilotage error in area navigation with vertical guidance was measured in a simulator for all combinations of four descent angles and four scale factors for the vertical guidance display for each of two pilot groups representing different experience levels. Performance was measured in terms of altitude error, cross-track error, airspeed error, procedural error and information processing rate on an independent side task. The results show that altitude tracking errors increase with descent angle and decrease as display scale factor becomes more sensitive. Altitude errors for airline transport pilots were reliably smaller than for commercial instrument pilots for most of the conditions tested.

WAUGH, J.P. *Pilot performance in a helicopter simulator*. Final Technical Memorandum. Human Engineering Laboratories, Aberdeen Proving Ground, Maryland, U.S.A. HEL TM-23-75, 1975.

Six U.S. Army I.R. helicopter pilots "flew" a difficult precision instrument flight pattern in a GAT-2H helicopter simulator. For each flight, each subject was given a different combination of thrust to weight, cyclic control sensitivity and cyclic spring centring force gradient condition, making up an incomplete balanced block experimental design. Deviations for several parameters were obtained during a series of trials. However, there were large variations in the results and none of the measurements chosen could be used satisfactorily either to predict performance or to indicate relative workload. A fresh approach is envisaged.

WEENER, E.F. *The effect of simulator dynamics on pilot response*. NASA CR-132459, 1974.

The effects of visual display dynamics on the altitude tracking performance of a pilot in a fixed-base simulator were studied. The subject attempted to maintain the same altitude as two aircraft positioned three hundred feet ahead, as in level formation flying. The horizon, together with the two leading aircraft, were represented symbolically on a CRT display. The subject's aircraft was disturbed by atmospheric turbulence. Two pilots took part and each flew under two substantially different longitudinal aircraft dynamics.

### Conclusions

The data indicates a relationship between the bandwidth of the display dynamics and the short period characteristics of the simulated plane. For an aircraft with a relatively fast pitch response the presence of altitude display dynamics with a bandwidth as high as five times the short period natural frequency, caused significant degradation of altitude tracking performance. However, for an aircraft with a slower pitch response, the presence of the display dynamics had no significant effect until the bandwidth was approximately twice the short-period natural frequency.

WEIR, D.H. and KLEIN, R.H. *The measurement and analysis of pilot scanning and control behaviour during simulated instrument approaches*. NASA CR-1535, 1970.

This report summarises research accomplished as one part of an overall programme aimed at developing models and methods for the analysis and synthesis of manual control displays. Measurement of pilot scanning and control response in a simulated instrument approach is reported. Seven commercial airline pilots flew Cat II approaches using pitch and roll motion in a fixed-base DC-8 simulator at the NASA Ames Research Centre. Data for four of the pilots is considered in this report. The conventional instrument panel and controls were used with simulated vertical gust and glide slope beam bend forcing functions. Dwell times, look rates, scan rates and fractional scanning workload were measured using an eye point-of-regard (EPR) system during flight director (zero reader) and localiser glide slope (manual) approaches. Both fixed and variable instrument range sensitivities were included. The scanning results showed the attitude and glide slope/localiser instruments to be primary during ILS approach, sharing 70-80 per cent of the pilot's attention. The glide slope/localiser instrument required shorter dwell times with a fixed instrument sensitivity. Significant differences in dwell time between pilots occurred only on the attitude instrument. With the flight director, glide path deviation errors were reduced and the flight director instrument dominated pilot attention (about 80 per cent). There were no apparent circulatory scanning patterns in any of the approaches. These EPR results were generally consistent with previous data, where meaningful comparisons could be made.

WEMPE, T.E. *Fixed-base simulator evaluation of a pilot's terrain-following display with various modes of presenting information*. NASA TN-D-1827, 1964.

The control dynamics of a small aircraft flying near sea level at Mach 1.2 were simulated on an analogue computer

connected to a two-axis side-arm controller and a CRT display. The pilot's task (using the visual display) was to guide the aircraft as closely as possible to simulated terrain while minimising a heading "error". Motion and environmental stresses were not simulated.

#### Conclusions

Comparative terrain-following performance measures for several display modes showed that performance improved progressively as:

1. The terrain points ahead were displayed as heights relative to the aircraft rather than as angles relative to the horizon,
2. The pitch angle was magnified compared to the scaling for standard attitude instruments in aircraft,
3. An indicator was added providing continuous information on maximum heights of the terrain 10 seconds ahead.

A 90-minute sustained terrain-following task revealed no major degradation in pilot performance.

WILCOXON, H.C. and DAVY, E. *Fidelity of simulation in Operational Flight Trainers. Part II. The effect of variation in control loadings on the training value of the SNJ OFT.* SDC 999-2-3b, 1954b.

#### Purpose

To find the effect of variation in control loadings on basic instrument and radio range procedure training. (Stage D, basic flight training).

#### Equipment

An SNJ OFT and an SNJ aircraft. (The control pressures of the standard OFT are designed to duplicate those of the SNJ aircraft).

#### Method

Students entering the basic instrument training course were divided into three groups viz.,

Group I was a standard pressure group (of 52 subjects) for whom the control loadings in the OFT were the normal ones.

Group II consisted of a low-pressure group (numbering 29) for whom the control loadings in the OFT were half the normal ones.

Group III was a high pressure group (numbering 27) for whom the control loadings in the OFT were one and a half times the normal ones.

All the students followed an experimental block syllabus on the OFT before comparative trials on the normally loaded controls of the SNJ aircraft.

#### Assessment

Students' deviations from prescribed tolerances on important aspects of basic instrument and radio range flight were used to obtain a proficiency index. Since equal amounts of simulator and flight training were required by students of each group to complete the syllabus, proficiency scores were compared to find whether the "modified" OFTs had had any effect on student performance. Comparisons were made using analysis of variance techniques.

#### Conclusions

1. Variations in control pressures had no significant effect on learning basic instrument or radio procedures. Students compensated for stick pressure differences.
2. Students objected to stiff or loose controls since they had to expend more effort to maintain control.

WILLIAMS, A.C. and ROSCOE, S.N. *Pilot performance in instrument flight as a function of the extent and distribution of the visible horizon.* SDC 71-16-3, 1949.

This experiment was designed to determine the differences in flight attitude control as a function of the two experimentally manipulated variables, extent and distribution of visible horizon. There were significant differences among subjects both in direction and attitude scores. In such experiments, individual differences in pilot performance are usually significant at the 5% level. The fact that these differences were significant at the 1% level in the present experiment is an indication of the relative homogeneity of ability of the nine pilots tested.

WOLF, J.D. *An experimental evaluation of aircraft displays for IFR steep-angle approaches.* Proceedings of IEEE-GMMS ERS International Symposium 'Man-Machine Systems', Cambridge, England, September 1969.

This is an investigation of display requirements for IFR steep-angle approaches and landing with 1975-80 era tactical rotary wing and V/STOL aircraft. The study was conducted with variable velocity simulations of the Bell UH-1 helicopter and the Ryan XV-5 ducted-fan VTOL aircraft. Alternative display formats representing both horizontal and vertical situation display concepts were developed and evaluated. Approach angle and profile characteristics were varied to find their effects on task performance and to increase the generality of display-comparison results obtained.

#### Conclusions

Results indicated that manually controlled IFR steep-angle approaches and landings are possible with all the display formats evaluated. Generally, PPI information display formats were found to yield more accurate piloting performance with both vehicles. Effects of approach profile variations were minor while effects of approach angle did vary as a function of the vehicle flown and the axis of error or performance measurement.

WULFECK, J.W., PROSIN, D.J. and BURGER, W.J. *Effect of a predictor display on carrier landing performance.*

*Part I: Experimental evaluation.* Final Report. AD-767982, 1973.

A three-phase programme was conducted to find the effect of a predictor display on carrier landing performance.

Phase A consisted of display development. Phase B consisted of display mechanisation, preliminary experimental-

tion and development of a detailed design for a formal experiment in Phase C to compare the predictor to a base-line display in a fixed-base F4 simulator with carrier qualified pilots as subjects. The report concludes the programme. Part I presents the results of the experiment conducted in Phase C.

YOUNG, L.L., JENSEN, R.S. and TRAICHE, C.W. *Use of a visual landing system in primary flight training.* ARL 73-26/AFOSR 73-17, 1973.

*Aim*

An exploratory study was made to find the potential usefulness of a visual landing system in a primary flight training programme, and to determine design and instructional changes which may be necessary to optimise the landing trainer.

*Method*

Thirty-eight flight-naive students were divided into three groups. Each received a different type of simulator landing instruction viz., (1) a visual landing system (2) standard GAT-1 and (3) control. The criterion was three consecutive unassisted landings in a Cherokee 140 aircraft. The primary measure was the flight instruction time needed to reach criterion.

*Conclusion*

Comments from flight instructors and students displayed optimism concerning the potential of the visual landing system as an aid to teaching landings.

## AIRCRAFT HANDLING

ACKLAM, D.J. *Flight simulator as a design tool*. Aircraft Engineering, 1972, 44, 4-8.

The author demonstrates how simulators contribute to the design of a new aircraft from early project studies through the detailed design stage to first flight and beyond into the development programme. Inevitably as the design of aircraft evolves, situations arise where unconventional or marginal handling qualities are likely to occur and no hard and fast criteria exist. Performance and handling qualities often have opposing requirements, e.g. good handling qualities often demand large tail surfaces. Therefore design becomes a compromise and the simulator enables the designer to make a decision avoiding the pitfalls of excess weight, drag, or complication on the one hand and unacceptable handling qualities on the other.

ADAMS, J.J., KINCAID, J.K. and BERGERON, H.P. *Determination of critical tracking tasks for a human pilot*. NASA TN D-3242, February 1966.

*Object*

To find the maximum amount of control element lag and the maximum and minimum control sensitivity that can be tolerated in a single-degree-of-freedom, manually controlled compensatory tracking task.

*Subjects*

Five NASA test pilots and one engineer served as subjects.

*Method*

A relatively easy-to-satisfy error criterion was used to establish the tolerable limit. An automatic controlled element parameter adjustment was used to find rapidly the limiting value of the parameter. An automatic model-matching method was used to find the transfer function of the subjects in these tests. The pilot's stick output was the input to a simulated controlled element. The output of the controlled element was summed with a random disturbance to form the system error. This system error was presented to the pilot on an oscilloscope as the difference between a moving horizontal line and a fixed reference mark. The pilot's task (using a pencil-type, spring-loaded, side-arm controller) was to keep the moving line aligned with the reference mark as closely as possible at all times.

*Conclusion*

Calculations of the closed-loop system characteristics, using the measured pilot transfer function, show that the system is being operated with neutral closed-loop stability in the maximum lag configuration, and that the pilot is greatly restricted in his ability to identify, and adjust to, variations in control sensitivity as controlled element lag is increased.

A'HARRAH, R.C. and SCHULZE, R.P. *An investigation of low-altitude high-speed flying and riding qualities of aircraft*. NA-62H-397, February 1963.

*Equipment*

The simulator used had a 12 feet vertical travel range and an acceleration capability of  $\pm 6G$ . It presented pitch, heave and roll motion. A F9F-8T aircraft was used for the flight trials.

*Subjects*

Eleven test pilots took part. Their ages ranged from 29 to 38 years. Six of them had previous simulator experience.

*Summary*

The authors have set out the results of a combined flight and simulator study of the handling and riding qualities problems associated with LAHS flight. Wide variations of longitudinal stability and control characteristics were evaluated and pilot performance was measured for a terrain-following task flown at varying levels of atmospheric turbulence. Pilot tolerance to gust-induced accelerations was obtained.

ARMSTRONG, B.D. *Difficulties with the simulation of aircraft landings*. RAE TR-68116, 1968.

A discussion of work being carried out at the Blind Landing Experimental Unit (BLEU) at Bedford is coupled with a literature survey to show that present standards of landing simulations are inadequate, particularly for low visibility research or training. Possible reasons are discussed and preliminary results are quoted from a series of exploratory tests at present in hand at BLEU. This paper is a general introduction to individual reports which will deal with each test in detail.

BARNES, A.G. *The objectives of simulation*. AGARD CP-79-70, 1971.

The author defines the objectives of simulation, used in a general sense, as:

1. To derive statements about the properties of a system which may be read across to the real world,
2. To provide a framework for the interpretation of experiments,
3. To improve the model, and
4. To suggest further experiments.

Flight simulation experiments provide for accelerated development of aircraft at reduced cost in that the trial and error processes of development may be carried out on the simulator, and the aircraft can then be modified in accordance with the results.

BARNES, A.G., HOUGHTON, D.E.A. and COLCLOUGH, C. *A simulator study of direct lift control (DLC)*. MOD CP-1199, 1970.

The authors describe a fixed-base simulator study of DLC as applied to the VC-10 aircraft. The practical limitations imposed by factors such as the small spoiler authority, the control lift, the power control dynamics and the c.g. range over which the systems must operate are included. A degree of improvement in longitudinal handling can be obtained from DLC, but it seems from this study that the most promising arrangement lies in the combination of DLC and a "manoeuvre boost" applied to the elevator. Confirmation by flight trials of the improved performance in the landing flare is needed because of the difficulty of simulating this phase of flight.

BELSLEY, S.E. *Pilot-vehicle system simulation*. AGARDograph 99, 1964.

The author outlines a procedure for conducting a meaningful simulation of a man-vehicle system. He illustrates the relationship of the various types of simulator to their use. The examples given are aimed at showing that, as the problem to be studied becomes more complex or the questions asked of the simulation become more quantitative, the simulator characteristics must become more flight-like. Although the "Advanced Simulator" does not now exist and may never exist in the eyes of the critical pilot, most of the characteristics desired of this type of simulator may be provided by the jet transport training simulator which affords a limited motion capability along with strong visual cues in the form of a projection system. However, rather than provide complete fidelity for all problems, it is more sensible to provide devices that are responsive to certain types of mission - advanced aircraft, space vehicle and hovering flight - and which will reproduce the dominant motions required for the problem in hand. Whenever possible variable stability and variable control system aircraft should be used to validate the results obtained with ground-based equipment.

BERGER, J.B., MEYER, R.P. and CARLTON, D.L. *Application of manned air combat simulation in the development of flight control requirements for weapon delivery*. Proceedings of AGARD FMP/GCP Symposium 'Flight Simulation/Guidance Systems Simulation', The Hague, Netherlands, October 1975.

Air combat simulations were conducted (1) to develop analytical pilot models that relate weapon delivery to the integrated aircraft/displays/sight/geometry system for air-to-air and air-to-ground weapons delivery tasks, (2) to validate and incorporate these pilot models in the Terminal Aerial Weapons Delivery Simulation (TAWDS) digital computer programme and (3) to use the TAWDS programme to find how aircraft flying qualities affect air-to-air and air-to-ground gunnery and bombing weapon delivery effectiveness. The TAWDS programme enables a digital simulation to be done on closed-loop weapon delivery systems under manual tracking control for the evaluation of weapon delivery accuracy. Tracking performance results, acquired from analytical pilot simulations are compared with those obtained from manned simulations and the Tactical Weapon Delivery test programmes. The evaluation of flying qualities for advanced fighter aircraft performance air-to-ground weapon delivery tasks in terms of weapon system effectiveness is shown to be feasible for determining flight control requirements.

BIHRLE, W. *Aircraft characteristics that influence the longitudinal handling qualities during a carrier approach*. AIAA 69-894, 1969.

Pilots from the Naval Air Test Centre performed about 7,000 visual landings on the Grumman motion simulator to evaluate the influence of the short-period frequency, damping ratio, load factor attainable per unit angle of attack, tail length, operation on the backside of the trimmed power required versus speed curve, and the engine thrust response on handling qualities. The influence of both an automatic power compensator and direct lift control system was also briefly investigated. Significantly, further experimental verification was obtained during this investigation for the theory and the control anticipation parameter (CAP) that relates the quantities involved in the man-machine precision control mechanism. A critical value for CAP was established for carrier landings, but it is applicable to all other precision control tasks since this value is based on a physiological limitation of man.

BRAY, R.S. and ANDERSON, S.B. *Simulation techniques used in investigating aircraft accidents*. Proceedings of R.Ae.S. Conference on Atmospheric Turbulence, London, England, May 1971.

The use of simulation techniques is discussed, first for the general case of a typical turbulence upset, to show how simulation techniques can be used to uncover possible reasons for the upset. Next, the techniques are applied to two specific accidents to show the degree of simulator sophistication needed to match the accident conditions properly. Then important factors are discussed that should be considered in using simulation for accident investigations.

BREUHAUS, W.O. and HARPER, R.P. *The selection of tasks and subjects for flight simulation experiments*. AGARD CP-79-70, 1971.

The purpose of flight simulation experiments is to estimate the results of a real-world situation. To do so it is essential to (1) select suitable evaluation tasks, and (2) to select and prepare the subjects. The limitations of some simulators directly affect the tasks which can be performed and hence affect the validity of the results. The ability of the pilot to produce valid and repeatable results can be no better than the accuracy with which the tasks represent the real-world situation. To obtain representative results the authors suggest:

- (a) The use of a good experimental design.
- (b) That extrapolations should be validated.
- (c) That aircrew comments should be noted and used in the analysis of data.
- (d) That we need to improve our understanding and modelling of the dynamic nature of the pilot - controller - vehicle - display system so that our predictive ability and analytical knowledge of this system may expand, and

- (e) That we need feedback of flight information so that we can find whether quantitative performance measures obtained from simulation agree with real-world results.

BREUL, H.T. *Simulator study of low-speed VTOL handling qualities in turbulence (Final Report)*. Grumman Aircraft Corporation, Bethpage, New York, U.S.A. Research Report RE 238, February, 1966.

An experimental study was performed to determine, from the pilot's point of view, the effects of certain stability derivatives, atmospheric turbulence, and control power on the handling qualities of VTOL aircraft. Using a flight simulator, qualified pilots evaluated 450 configurations in the task of moving the craft from one hover spot to another. The simulator consisted of a cockpit providing motion in roll and pitch and an optical display system providing an illusion of motion in the remaining four degrees of freedom.

*Conclusions*

The primary conclusion drawn from the study is that speed stability, either lateral or longitudinal, strongly influences a hovering vehicle's control power and angular rate damping requirements. Furthermore, lateral and longitudinal requirements are found to be similar when the effects of speed stability are taken into account.

BROWN, A.D. *Category 2 -- A simulation study of approaches and landings at night*. RAE Tech. Memo: Avionics 59 (BLEU), 1970.

The execution and preliminary results of a simulator experiment to investigate the problems of aircraft operating in Category 2 conditions are described. Five RAF, one Navy and thirteen civilian pilots performed over 500 approaches in a fixed-base simulator. The effects of decision height, contact time, lateral offset, visual sequence and visual segment on the approach success (ratio of landings to approaches) are examined and a curve relating this parameter to visual segments, the predominant factor, is determined. The influence of different visual sequences on pilot performance during approach and landing is also considered. Some of the crew techniques used appeared to have certain deficiencies. Pilots expressed their opinions on many aspects of the simulation and equipment on questionnaire forms.

BROWN, A.D. *An examination of simulator landing problems*. AIAA 70-344, 1970.

The landing performance of pilots using the BLEU (Bedford) static cockpit is compared with flight data for night conditions in clear and limited visibility. The instant of TD is considered for descent rate, longitudinal position, lateral rate, bank angle, lateral position and pitch angle. Since the first four showed significant differences, flight and simulator experiments were done to determine whether these differences could be caused by inherent visual display limitations. Restricted peripheral vision, monocular vision, and pilot-display viewing distance were examined but no significant effects were found to explain the simulator results. It is concluded that cockpit motion is necessary to achieve realistic landing performances.

CHUBBOY, R.A. *Programme plan to develop airworthiness standards for STOL aircraft*. Canadian Aeronautics and Space Journal, 1973, 19, 289-295.

The author outlines a joint French/UK/US simulator programme to develop criteria for supporting airworthiness standards for powered-lift transport-category aircraft. STOL considerations, test methodology and some preliminary results obtained on the Baseline Brequet 941 are discussed. The following impressions are significant. Multiple configuration changes following baulked landing and/or one engine inoperative go-around may not pose a problem for STOL aircraft. Thrust response in the landing approach seems to influence man/machine performance more than thrust margin, especially on go-around. Lateral/directional characteristics of the powered-lift aircraft are critical, especially during flare and immediately following TD in crosswind and/or turbulence.

COOLES, H.D. *The dynamic flight simulator -- a general purpose research tool*. Proceedings of Instrument Society of America Eleventh National Aerospace Instrument Symposium, Los Angeles, U.S.A., October 1965.

The author examines the performance requirements for effective simulation. Some of the hardware, instrument needs and techniques used in dynamic simulation for man-machine system research are discussed. Two North American Aviation simulators, a Grumman simulator and an Ames Research Centre VTOL simulator are illustrated and discussed.

COOPER, G.E. and DRINKWATER, F.J. *Pilot assessment aspects of simulation*. NASA TM-X-66583, 1971.

The authors stress the importance of pilot ratings in the evaluation of aircraft handling qualities. Critical questions raised by pilots are examined and discussed in order to develop solutions and improve understanding. It is essential to involve the pilot at an early stage in developing a simulation programme by considering his complaints about simulation experiences, the planning and conducting of experiments, the simulation facility and the analysis of results.

CREER, B.Y., STEWART, J.D., MERRICK, R.B. and DRINKWATER, F.J. *A pilot opinion study of lateral control requirements for a fighter-type aircraft*. NASA M-1-29-59A, 1959.

Two fundamental parameters affecting pilot opinion on aircraft roll performance were determined. In addition, a handling qualities criterion was formulated for the lateral control of fighter aircraft flying in their combat-speed

range. For this investigation two types of simulator were used, viz., a fixed-base cockpit (Sabre) and a rolling cockpit. Additionally, flight tests were made in a variety of aircraft which included a propeller-driven fighter, straight-wing trainers, interceptors of both the swept-wing and delta-wing type and a variable stability plane.

#### *Findings*

1. It was shown on the simulators that pilot opinion of the lateral controllability of fighter-type aircraft would correlate with a roll damping parameter and an aileron power parameter which was written in terms of roll acceleration. In addition, boundaries in terms of these two parameters were determined for satisfactory, unsatisfactory and unacceptable roll performance.
2. From the flight investigation it was found that the roll performance criterion derived from the rolling simulator will give a fairly accurate prediction of the actual in-flight pilot opinion, provided the degree of coupling between the airplane modes of motion was not excessive.
3. It appears that the bank angle change at the end of one second, following an abrupt aileron input by the pilot, is deficient as a specification covering the lateral controllability of fighter aircraft flying in their combat-speed range. This is mainly because the specification fails to impose a roll damping requirement and because it does not recognise that an excess of aileron power can be detrimental.
4. The wing-tip helix angle could not be used as a general measure of the roll performance of fighter aircraft flying in their combat-speed range.
5. The fixed-base simulator results were in close agreement with the flight and the rolling simulator results, provided that the angular acceleration forces on the pilot were not large. When the accelerations were large, the results tended to differ because the "g" forces interfered with the pilot's control ability in the rolling simulator and in flight.

DECKERT, W.H. and HOLZHAUSER, C.A. *Evaluation of V/STOL research aircraft design*. SAE 730947, 1973.

The authors discuss the evolution and evaluation of direct jet-lift V/STOL transport aircraft designs and the use of the moving-base simulator as a design tool for developing satisfactory V/STOL stabilisation and propulsion/control systems. They examine problems of simultaneous decelerating/descent steep curved landing approaches under IF conditions. Simulation results are compared with flight results obtained with the DO-31 V/STOL research transport.

DILLENSCHNEIDER, P.G. and SHAW, A.W. *Use of ground-based simulators in aircraft design*. Journal of Aircraft, 1971, 8, 113-119.

The growth in simulation technology and the extension of this technology to engineering-oriented simulation is discussed. Basic differences between simulation used for training and engineering design are identified. Three specific engineering-oriented simulations are presented: (1) an air combat simulation used to evaluate the effect of changes in aircraft characteristics on air combat effectiveness, (2) approach and landing on board an aircraft carrier at night to evaluate handling qualities in this critical tracking task, and (3) a V/STOL assault transport simulation used to tailor aircraft dynamics, control feel system characteristics and flying qualities over the complete flight envelope.

DRAKE, D.E., BERG, R.A., TEPER, G.L. and SHIRLEY, A. *A flight simulator study of STOL transport lateral control characteristics*. FAA RD-70-61, 1970.

#### *Aims*

To identify the significant STOL transport terminal-area lateral control considerations and to establish appropriate flight characteristics criteria.

#### *Equipment*

The NASA S-16 Moving-Cab Transport Simulator was used. This vehicle has the flight characteristics of a Breguet-941 STOL transport.

#### *Subjects*

Five test pilots carried out the runs.

#### *Method*

The investigation was done in two parts, viz:—

1. An analysis of applicable existing data was carried out to identify the significant lateral control considerations, and
2. A simulator programme was conducted covering a wide range of vehicle aerodynamics and physical characteristics representative of practical STOL transports ranging in size from 25,000 to 130,000 pounds. In addition to pilot opinion ratings, performance data and pilot control activity were tabulated for each run.

#### *Conclusion*

On the basis of the simulator tests and the correlation of the results with already existing data, criteria were established for minimum satisfactory and minimum acceptable levels of those characteristics considered to be significant for STOL transport terminal-area lateral control.

DUSTERBERRY, J.C. *Manned flight simulation facilities*. AGARDograph 99, 1964.

The design, development and operation of simulation facilities depend on the co-operation of people with diverse skills, e.g. engineers, research scientists and pilots. From an engineering aspect, the author discusses the tailoring of simulators and associated equipment to suit specific needs. He cites examples. On the experimental side, the

researcher must confine the equipment used to that which produces the minimum necessary cues. Refinements which produce greater realism of parts of the task which are not pertinent to the research problem in hand can absorb time, money and effort, and yet have no valid effect on the results. As regards subjects the research pilot, besides contributing subjective comments during the test runs, is an important member of the research team in the initial stages of the experiment. He knows, not just that things are wrong, but he has the insight and training to know what is wrong with the simulation and so he is of invaluable help in setting up the experiment.

FAYE, A.E. *Attitude control requirements for hovering, determined through the use of a piloted flight simulator.* NASA TN-D-742, 1961.

The aim was to establish attitude control requirements for VTOL hovering flight. Controllability boundaries of control power and damping values were established about each of the three axes, one at a time, under ideal conditions. These single-axis boundaries shifted and became more restricted when simultaneous control about two-axes was presented to the pilot with the controls harmonised, or when gyroscopic coupling was added. Gyroscopic coupling between pitch and yaw resulted in a rapid deterioration of controllability with increasing amounts of coupling, especially when the damping was reduced to low values. Simulator two-axes results and VTOL plane all-axes results correlate well.

GALLAGHER, J.T. *Simulation and analysis in establishing flying qualities criteria.* AGARD CP-106, 1971.

Existing flying qualities criteria specified in MIL-F-8785B (ASG) have been established using open and closed-loop analysis techniques, ground-based simulation, in-flight simulation and experience from flight testing in-service airplanes. While the specification is comprehensive, there are areas where the requirements need improving. The two more obvious areas are associated with the effects of turbulence on flying qualities and the interaction of control system dynamics with airplane characteristics. It has been demonstrated that ground-based simulation and analysis hold the promise for better specification of turbulence effects, and in-flight simulation and analysis may be useful in specifying total system flying qualities criteria. With current technology, the improved in-flight and ground-based simulator facilities necessary for this research can be provided.

GERKEN, G.J. and STONE, J.R. *Piloted power-approach simulation.* Proceedings of Fourth Annual Symposium of the Society of Flight Test Engineers, Las Vegas, Nevada, U.S.A., August 1973.

A simulator was used to evaluate the handling qualities during a power approach to landing of the B-1 variable sweep bomber. Non-linear pitching moment characteristics, flight control system performance, pitch transients and roll control were investigated. A pilot model/air vehicle closed-loop analysis was also conducted to obtain Cooper-Harper pilot ratings, pilot model parameters and closed-loop pitch tracking error. It is believed that the B-1 will have acceptable handling qualities during a power approach after some flight control system tuning.

GRANTHAM, W.D. and DEAL, P.L. *A piloted fixed-base simulator study of low-speed flight characteristics of an arrow-wing supersonic transport design.* NASA TN-D-4277, 1968.

The authors carried out a fixed-base simulator study to find the low-speed flight characteristics of an arrow-wing SST configuration. The transport-type cockpit was equipped with normal flight controls and a flight instrument display representative of those found in a transport aircraft. The simulator did not have an external visual display. The primary task used during the evaluation was instrument approach. The flare and TD characteristics were not evaluated.

#### *Findings*

The results indicated that, although the longitudinal short-period damping ratio was at a good level (0.84), the pitch damping appeared low to the pilot because of the low frequency and the sluggish pitch response made the longitudinal handling qualities of the basic configuration unsatisfactory (Cooper rating of 6.5). When the static stability, the damping in pitch, the elevator effectiveness, and the elevator-to-control gearing were increased by a sufficient amount, the Cooper rating was improved to 2.5. The lateral-directional handling qualities of the basic configuration were "unacceptable" (Cooper rating of 8.5) because of the poor roll control characteristics and the uncontrollable Dutch roll. When the effective dihedral was decreased by a sufficient amount and the damping moment in roll and yaw was increased sufficiently, the Cooper rating was improved to 2.5.

GRANTHAM, W.D. and DEAL, P.L. *Simulator study of minimum acceptable level of longitudinal stability for a STOL configuration during landing approach.* NASA TN-D-7733, 1974.

The purpose was to find the minimum acceptable level of longitudinal stability for a representative turboprop STOL transport plane during the landing approach. Real-time digital simulation techniques were used. The computer was programmed for six-degrees-of-motion freedom. The aerodynamic inputs were based on wind tunnel data. The primary piloting task was an instrument approach to a breakout at 200 feet.

GRANTHAM, W.D., NGUYEN, L.T. and DEAL, P.L. *Simulation of decelerating landing approaches on an externally blown flap STOL transport airplane*. NASA TN-D-7463, 1974.

The authors carried out a fixed-base simulator study about decelerating landing approaches on a representative high wing STOL transport. Real-time digital simulation techniques were used. The computer provided six-degrees-of-motion freedom and the aerodynamic inputs were based on wind tunnel data. The pilot's task was to capture the localiser and glideslope and to maintain them as closely as possible while decelerating from 140 knots to 75 knots under IFR conditions.

GRANTHAM, W.D., NGUYEN, L.T., PATTON, J.M., DEAL, P.L., CHAMPINE, R.A. and CARTER, C.R. *Fixed-base simulator study of an externally blown flap STOL transport airplane during approach and landing*. NASA TN-D-6898, 1972.

A fixed-base simulator study was carried out to find the flight characteristics of a representative high wing STOL transport during approach and landing. The plane had four high bypass fan jets and an external-flow jet flap. The simulator computer provided six-degrees-of-motion freedom based on measured wind tunnel data. A visual display of a STOL airport was provided for the flare and TD stage. The primary piloting task was an instrument approach to a breakout at 200 feet with a visual landing.

#### Findings

1. The results indicated that satisfactory handling qualities could be obtained but considerable augmentation was required. The pilots could easily capture and track the localiser and glideslope for any of the simulated approach angles ( $4^\circ$ ,  $6^\circ$ ,  $7\frac{1}{2}^\circ$  and  $9^\circ$ ) and the pilot rating for the instrument approach task remained the same for all approach angles. However, the maximum glideslope from which the airplane should be landed was  $6^\circ$  and, in order to have any confidence in making consistently precise landings, a two-segment approach to a glideslope of  $4^\circ$  should be used.
2. With all the augmentation systems operative, the loss of a critical engine during an instrument approach posed no problems in tracking the localiser and glideslope. However, this engine-out condition did present problems in making a precision landing.
3. If the STOL airplane does not have crosswind gear, a  $90^\circ$  crosswind of about 20 knots is the largest a pilot could handle and maintain adequate rudder control margins.

GRANTHAM, W.D., SOMMER, R.W. and DEAL, P.L. *Simulator study of flight characteristics of a jet-flap STOL transport airplane during approach and landing*. NASA TN-D-6225, 1971.

A fixed-base simulator study was conducted to obtain knowledge of the low-speed handling qualities of a STOL transport configuration equipped with an external flow jet-flap and high bypass ratio turbofan engines. The attached computer provided six-degree-of-motion equations based on wind tunnel data. A visual display of a STOL airport was provided. The primary piloting task was an instrument approach to a breakout at 200 feet with a visual landing.

#### Findings

The results indicated that satisfactory handling qualities could be obtained but considerable stability augmentation was required. This was particularly true for the lateral-directional axes where unacceptable Dutch roll characteristics, poor turn co-ordination and poor roll control were encountered. The use of autospeed control greatly simplified the piloting task and was considered to be mandatory for satisfactory instrument approaches. With autospeed control engaged, the glideslope could easily be captured and tracked for descent angles as large as  $7.5^\circ$ . The results also showed that, with the type and amount of stability augmentation used to produce satisfactory flying qualities, severe limitations on cross-wind landing performance may result.

HEFFLEY, R.K., JEWELL, W.F., STAPLEFORD, R.L., CRAIG, S.J., HYNES, C.S. and SCOTT, B.C. *A STOL airworthiness investigation using a simulation of a deflected slipstream transport. Vol.3: Breguet 941S simulation model*.

Simulations were conducted to determine the airworthiness of the Breguet 941S transport aircraft. The areas investigated included: (1) acceleration to TO and initial climbout, (2) transition from cruise to STOL approach, (3) IFR/VFR approach, (4) flare, TD and landing roll, (5) missed approach and (6) high lift stalls. The model was developed by matching flight data for the Breguet 941S aircraft.

When this was not possible, wind tunnel data and engineering estimates were used. Results of the simulation are presented in graph and tabular form. Reference should be made to Stapleford, R.L. et al (1974).

Stapleford, R.L., Heffley, R.K., Rumold, R.C., Hynes, C.S. and Scott, B.C. *A STOL airworthiness investigation using a simulation of a deflected slipstream transport. Vol.1: Summary of results and airworthiness implications*. NASA TM-X-62392, 1974.

Stapleford, R.L., Heffley, R.K., Jewell, W.F., Lehman, J.M., Hynes, C.S. and Scott, B.C. *A STOL airworthiness investigation using a simulation of a deflected slipstream transport. Vol.2: Simulation data and analysis*. NASA TM-X-62393, 1974.

HOLZHAUSER, C.A., INNIS, R.C. and VOMASKE, R.F. *A flight and simulator study of the handling qualities of a deflected slipstream STOL seaplane having four propellers and boundary layer control*. NASA TN-D-2966, 1965.

#### Equipment

The Ames Moving-Base Transport Simulator (six-degrees-of-motion freedom) was used. It has limited movement in pitch and roll. It was equipped with instrument displays and flight controls similar to those in the UF-XS air-

craft under investigation. A Dalto visual simulator, a closed-circuit TV system with the camera servo-driven over a model runway, projected the approach lighting and runway as would be seen in hazy half-mile visibility. The equipment could not simulate a sea landing.

*Method*

Flight and simulator tests were made to study low-speed handling qualities, potential stall problem areas, and causes of deficiencies and their solutions. Tests of the STOL seaplane were made in the 50 to 60 knot speed range with Automatic Stabilisation Equipment engaged and disengaged. During the simulation, several stability and damping derivatives were varied and evaluated.

*Notes*

The simulator tests were useful in providing a preliminary evaluation and in studying the causes of deficiencies and their remedies. Good correlation was obtained between the simulator and flight results with the exception that the sideslip excursions during manoeuvring were larger in flight than on the simulator.

JACOBSEN, R.A. and GRIEF, R.K. *Simulation study of the lift-roll coupling problem for hovering VTOL aircraft.* NASA TN-D-6906, 1972.

*Subject*

A NASA research pilot.

*Equipment*

The Ames six-degrees-of-motion freedom simulator was used. The configuration tested had three thrust sources, one on the roll axis and two laterally displaced and equi-distant from the roll axis. The outboard thrust sources provided roll control whereas all three sources provided height control.

*Method*

The pilot had to perform precision hovering and manoeuvring within the limits of simulator travel. He also did lateral quick-stops and roll reversals to help assess the vehicle's handling qualities. The lateral quick-stop is performed by starting from a steady hover, translating about 15 feet and re-establishing a steady hover. The period of the quick-stop manoeuvre was about 3.5 seconds. The roll reversal was a command roll oscillation of about 3 cycles with a period of about 1.5 seconds.

*Conclusion*

Results showed that handling qualities are affected not only by the occurrence of lift-roll (dependent on both variables) but also by the severity of the coupling (dependent on the coupling parameter alone). However, the advantages of differential thrust for control can be retained with careful design.

JENKINS, M.W.M. and HACKETT, J.E. *A pilot-in-the-loop visual simulation of trailing vortex encounters at low speed.* AIAA 75-104, 1975.

A fixed-base visual simulator having a transport cockpit was used to explore piloting encounters of a Hercules (C-130) flying in the wake of a Galaxy (C-5A). About 80 flight conditions were flown through a range of vortex strengths, core radii, spatial orientations, direction of rotation and encounter altitudes. All were at low speed on the final approach. The roll control power of the encountering aircraft was varied from 75 to 125% of its nominal value. Twenty channels of data were recorded and a film showing typical gyrations during encounter was taken. Vortex-lattice modelling techniques were used to update the forces and moments on the penetrating aircraft. The experiment established the feasibility of performing realistic simulation evaluations of the hazards of vortex encounters. It also established the feasibility of digitally updating the encounter dynamics in real time, thus permitting the pilot to perform visual tasks.

JOHNSON, W.A. and CRAIG, S.J. *Configuration management during transition for a powered-lift STOL aircraft.* AIAA 74-836, 1974.

The authors present the analytical and moving-base simulation results of a study to improve flight safety and operations of V/STOL type aircraft. One significant accomplishment has been the concept and implementation of a configuration management flight control system designed to take the guesswork out of, and improve the operational safety of, transition flight in the region from cruise to STOL.

JOHNSON, W.A., CRAIG, S.J. and ASKENAS, I.L. *Analysis and moving-base simulation of transition configuration management aspects of a powered-lift aircraft.* NASA CR-114698, 1973.

The authors studied the implementation of a configuration management flight control system designed to take the guesswork out of, and improve the operational safety of, transition flight in the region from cruise to STOL. Potential improvements in the trim configuration management aspects of the transition process are described.

JOHNSTON, D.E. and HOGGE, J.R. *The effect of non-symmetric flight on aircraft high angle of attack handling qualities and departure characteristics.* AIAA 74-792, 1974.

Analysis and simulation of an aircraft in asymmetric flight has resulted in identification of new open- and closed-loop parameters which relate to a coupled longitudinal-lateral divergence known as nose slice departure. The coupling produces non-minimum phase zeros in the pitch attitude at angles of attack below that for stall, and at relatively small sideslip angles. Pilot control of pitch attitude via elevator then produces a lateral divergence. The phenomenon is traced through the equation of motion, effective stability derivative, transfer function, and root

aerodynamic flow relationships. The results are verified by open- and closed-loop time histories from a non-linear six-degrees-of-freedom digital simulation and by fixed-base piloted simulation.

JONES, J.G. and TOMLINSON, B.N. *The representation of low altitude atmospheric turbulence in piloted ground-based simulators*. RAE TR-71198, 1971.

Several aspects of the simulation of flight in turbulence are reviewed including mathematical models of aircraft response to turbulence and the subjective reactions of the pilot. Pilots appear to be particularly sensitive to large intermittent peaks in the aircraft's response. Conventional gust generators which produce Gaussian properties do not adequately represent the intermittent structure of atmospheric turbulence. A proposed design for an improved gust generator incorporating non-linear transformation of a Gaussian process is outlined.

KAESTNER, R. *On the effect of reliability of simulation results on the methodology of flight testing and simulation*. NASA TT-F-15175, 1973.

Various methods of flight simulation are described and a comparison of the results obtained using flight simulators are discussed. The VAK 191 B aircraft is used as an example of typical TOL performance for STOL aircraft.

Diagrams of the aircraft attitude control during transition phases following TO and during landing approach are provided. Techniques used by the test pilot in conducting the flight tests are described.

KESLER, D.F., MURAKOSHI, A.Y. and SINACORI, J.B. *Flight simulation of the Model 347 advanced tandem-rotor helicopter*. Final Report, July 1972–October 1973. U.S. Army Air Mobility R & D Laboratories, Fort Eustis, Virginia, U.S.A. AAMRDL TR-74-21, 1974.

The purpose was to define important flight control system design and handling qualities criteria for moving loads suspended beneath tandem-rotor heavy-lift helicopters. This involved the use of a simulator. Methods used in developing data included theoretical analyses, acquisition and evaluation of wind tunnel and flight test data, derivation of motion equations, analysis of slung-load carrying problems and the simulation of a Model 347 helicopter carrying external loads, using Northrop's large-amplitude moving-base simulator and its associated hybrid computers.

KRAFT, C.L. and ELWORTH, C. *Night visual approaches in air transportation*. Proceedings of IEEE-GMMS ERS International Symposium 'Man-Machine Systems', Cambridge, England, September 1969.

Research with a night visual approach simulator suggests that about 16% of air transport accidents may be dependent on a descent path which nulls out some visual information, and a delay in relative motion supplement of this information. The missing topographic information allows incorrect interpretations of altitude and distance. Most operational examples of this class of accident include information about crew distractions, critical intrusions and workloads. The two-part hypothesis has been tested in a series of experimental investigations. The independent variables studied include city topography, distribution of city lights, approach length, initial altitude, brightness attenuation, crew workload and requested approach path. The performance of senior instructor pilots was measured as these variables influenced their approach performance, without altimetry, over dark land or water toward illuminated city/airfield situations. The dependent measures were generated altitudes, estimated altitudes and detection and reporting of other traffic.

KURKOWSKI, R.L., FICHTL, G.H. and GERA, J. *Development of turbulence and wind-shear models for simulator application*. NASA SP-270, 1971.

Investigations of handling and control problems in rough air and wind-shear can be accomplished effectively on simulators but this requires good models of the atmospheric disturbances. The authors present information on some continuing studies aimed at producing realistic models of turbulence and wind-shears for handling qualities studies. These studies include a simulator evaluation of analytical models of turbulence which have non-Gaussian gust disturbances, a statistical analysis of wind-shear and a brief evaluation of wind-shear on aircraft operations.

MARR, R.L. and RODERICK, W.E.B. *Handling qualities evaluation of the X-15 tilt rotor aircraft*. AHS Preprint 840, May 1974.

Handling quality evaluations of the X-15 tilt rotor aircraft have used model testing digital flight simulation, moving-base simulation and a variable-stability helicopter. Proper simulation of visual cues and control system dynamics were found to be very important for the correct interpretation of the aircraft characteristics. The Canadian NRC in-flight simulator, a Bell Model 205A-1 helicopter, was used to compare the collective stick with an airplane throttle lever for controlling the height of the tilt rotor aircraft in helicopter mode.

McLAUGHLIN, M.D. and WHITTEN, J.B. *Pilot evaluation of dynamic stability characteristics of a supersonic transport in cruising flight using a fixed-base simulator*. NASA TN-D-2436, 1964.

#### *Equipment*

A fixed-base cockpit with centre yoke and quadrant throttle control. There was no external visual attachment.

#### *Method*

The authors attempted to define the problems connected with supersonic cruising flight at high altitude and to obtain pilot ratings for conditions of low stability and damping. The investigation was done in two parts -- studies

of the longitudinal and the lateral directional stability characteristics. When investigating one mode the stability and damping of the other mode was increased to a "satisfactory" level. The conditions simulated were Mach 3 cruising flights at 70,000 feet and, during these, the pilot executed routine control tasks such as turns onto headings, straight and level flight and changes in altitude. His Cooper scale rating for the handling qualities was used to evaluate the configuration being investigated.

MENDELA, D.K. *Simulator investigation of the VTOL transport*. Journal of Aircraft, 1971, 8(10), 783-789.

Extensive simulation trials were carried out to explore the handling and performance qualities of a future civil VTOL aircraft. The simulated aircraft was a slender delta fitted with four banks of lift engines representing sixteen lift fan engines located on both sides of the fuselage. Thrust vectoring and thrust modulation were assumed for aircraft control in VTOL phases of flight and conventional aerodynamic surfaces in wing-borne flight. The simulator cockpit was equipped with the conventional dual flying controls and instrument panels typical of current jet airliners, but with some minor modifications to suit the VTOL role. Engine controls were modified as necessary and a simple HUD was incorporated. An analogue computer was used to provide six-degrees-of-motion freedom. Test pilots with current jet VTOL aircraft and helicopter experience took part in the trials. The results indicated that the introduction of a fail-safe autostabilisation system into VTOL transport may be necessary in roll, pitch, yaw and heave. Very steep and vertical flight profiles, considered necessary to meet noise abatement rules during city centre operations, were studied, and these proved to be feasible. Double lift fan engine failures could be controlled providing, at least, attitude demand autostabilisation system in roll and pitch was available. Particular attention was given to the cockpit controls layout and to the head-up display. A gradual introduction of more advanced instruments and electronic visual displays into V/STOL aircraft may become necessary, and the present Terminal Guidance and ATC will need to be adapted to facilitate VTOL operations.

MIDDLETON, D.B. and BERGERON, H.P. *A compilation and analysis of typical approach and landing data for a simulator study of an externally blown flap STOL aircraft*. NASA TN-D-7497, 1974.

A piloted simulated study has been made of typical landing approaches with an externally blown flap STOL aircraft to ascertain a realistic dispersion of parameter values at both the flare-window and TD. The study was performed with a fixed-base simulator using standard cockpit instrumentation. Six levels of stability and control augmentation were tested during a total of 60 approaches (10 at each level). A detailed supplement containing computer printouts of the flare-window and TD conditions of all 60 runs has been prepared.

MIDDLETON, D.B., HURT, G.J., BERGERON, H.P., PATTON, J.M., DEAL, P.L. and CHAMPINE, R.A. *Motion-base simulator study of control of an externally blown flap STOL transport aircraft after failure of an outboard engine during landing approach*. NASA TN-D-8026, 1975.

A motion simulator study of the problems of recovery and landing of a STOL aircraft after failure of an outboard engine during final approach was made. The approaches were at 75 knots along a six-degree glideslope. The engine was failed at low altitude and the option to overshoot was not allowed. The aircraft has four high-bypass-ratio fan-jet engines exhausting against large triple-slotted wing flaps to produce additional lift. It was simulated using each of three control systems. A visual system simulating a STOL airport was used during part of the study. Also a simple head-up display, superimposed on the airport landing scene, was used by the pilots to make some of the recoveries following an engine failure. The results indicated that the variation in visual cues and/or motion cues had little effect on the outcome of a recovery, but they did have some effect on the pilot's response and control patterns.

MILLER, G.E. *New longitudinal handling qualities data - carrier approaches*. AIAA 69-897, 1969.

Results of a flying qualities research programme are given. Navy test pilot evaluations in the form of Cooper ratings and specific comments on several longitudinal handling characteristics were obtained for a simulated carrier landing task. The investigation was of a variable stability aircraft which simulated the longitudinal short period response characteristics and the effects of atmospheric turbulence. The flying qualities associated with variations in short period frequency, lift curve slope, and the use of direct lift control are presented. The data was compared with similar data from flight and simulator tests. A gradual decline in handling qualities was found for reductions in short period frequency and lift curve slope. Direct lift control using a thumb controller was found to be desirable for this task on all configurations.

MILLER, G.K. and DEAL, P.L. *Moving-base visual simulation study of decoupled controls during approach and landing of a STOL transport aircraft*. NASA TN-D-7790, 1975.

The authors used a six-degree-of-motion-freedom simulator with STOL aerodynamic characteristics based on wind tunnel data. The flight instrumentation included a localiser and a flight director which was used to capture and to maintain a two-segment glideslope. A closed-circuit TV display of a STOL port provided visual cues during simulations of the approach and landing. The decoupled longitudinal controls used constant pre-filter and feedback gains to provide steady-state decoupling of flight-path angle, pitch angle and forward velocity. The pilots were enthusiastic about the decoupled longitudinal controls and believed that the simulator was an aid in evaluating the decoupled controls, although a minimum turbulence level with an RMS gust intensity of one foot/sec was required to mask undesirable characteristics of the simulator.

MILLER, G.K., DEAL, P.L. and CHAMPINE, R.A. *Fixed-base simulation study of decoupled controls during approach and landing of a STOL transport airplane*. NASA TN-D-7363, 1974.

The authors conducted a fixed-base visual simulator study to evaluate the use of decoupled controls as a means for reducing pilot workload during approach and landing of an externally blown jet-flap STOL transport. Six-degrees-of-motion freedom were employed with the aerodynamic characteristics based on wind tunnel data. The primary piloting task was to use a flight director to capture and maintain a two-segment glideslope, with a CCTV display of a STOL airport used during simulations of the flare and landing. The decoupled longitudinal controls used constant pre-filter and feedback gains to provide steady-state decoupling of flight path angle, pitch angle and forward velocity. The pilots were enthusiastic about the decoupled longitudinal controls but believed the decoupled concept offered no significant advantage over conventional controls in the lateral modes.

NAVE, R.L. *A pilot/LSO simulation conducted to investigate aircraft wave-off performance and to determine the ability of the landing signal officer to judge aircraft approaches*. Final Report. NASA 74112-30, 1974.

A fixed-base carrier landing simulation involving both a pilot and a landing signal officer (LSO) was carried out to investigate aircraft wave-off performance and to evaluate the functions of the LSO. Minimum aircraft design requirements are recommended, based on the simulation results.

NEWELL, F.D. *Ground simulator evaluations of coupled roll-spiral mode effects on aircraft handling qualities*. Cornell Aeronautical Laboratories Inc., Buffalo, New York, U.S.A. Report TC 1921-F-1, March 1965.

Using a fixed-base simulator, the author examined the lateral handling qualities of fighter aircraft on an IFR mission. The suitability of a wide range of roll and spiral mode root locations was investigated, emphasis being placed on determining the effects of complex roll-spiral roots. These roots were produced with several feasible combinations of stability derivatives. Interaction effects of Dutch roll were examined, including the effects of the proximity of these roots to the complex roll-spiral mode roots. Assessment of the flying qualities is reported in terms of comments and ratings given by two pilots. In general the complex roll-spiral configurations evaluated were too difficult to control in roll to consider their handling quality characteristics as acceptable for fighter aircraft.

NIEUWENHUIJSE, A.W. and FRANKLIN, J.A. *A simulator investigation of engine failure compensation for powered-lift STOL aircraft*. NASA TM-X-62363, 1974.

The purpose was to determine the influence of engine failure compensation on recovery from engine-out during the landing approach and on the precision of the subsequent STOL landing. Aspects studied include:

1. Cockpit warning lights to cue the pilot of an engine failure.
2. Programmed thrust and roll trim compensation.
3. Thrust command, and
4. Flight path stabilisation.

The aircraft simulated was a 150 passenger four-engine blown flap civil STOL transport having a 90 p.s.f. wing loading and a 0.56 thrust to weight ratio. Results indicate that the combination of thrust command and flight path stabilisation offered the best engine-out landing performance in turbulence and did so over the entire range of altitudes for which engine failures occurred.

NYLEN, W.E. *Engineering simulation development and evaluation of the two-segment noise abatement approach conducted in a B-727-222 flight simulator*. NASA CR-137594, 1974.

Profile modification as a means of reducing ground level noise from jet aircraft in the landing approach was evaluated. When the system characteristics and aircraft interface had been defined, they were programmed into a United Airlines B-727 simulator, permitting data to be recorded in real time on a line printer, a 14-channel oscillograph and an x-y plotter. The investigation included a detailed study of the effects of varying the profile parameters and an analysis of the effects of systems failures and mismanagement. Each of the profile variables was independently examined for its effect on safety, repeatability, pilot workload and ground noise level. The profile variables were then combined to develop a small family of two-segment profiles of approximately equal operational and noise abatement merit.

Van OOSTEROM, T. *Measurements on the relation between magnitude and duration, and on the rate of application of the control forces achieved by pilots in simulated manoeuvres*. AGARD R-241, 1959.

*Purpose*

To achieve data useful for the appreciation of the handling and control characteristics of an aircraft.

*Subjects*

Twenty-seven military and civil pilots took part in TEST 1 and 135 pilots participated in TEST 2.

*Equipment*

The test rig consisted of a modified centre section of a Harvard aircraft. The front cockpit was unaltered, but the control stick in the rear cockpit was replaced by a column fitted with a control wheel. Whenever the latter was used, rotation of the torsion tube connecting both control columns was blocked. The pilot's seats were adjustable

in the vertical direction and the rudder pedals in a horizontal plane. The control system was spring-loaded. In the rig for TEST 1, the control forces were counter-balanced and measured by direct-reading balances. In the rig for TEST 2, the force-time relation was derived from multi-channel oscillograph recordings.

#### Method

TEST 1 Measurements were made of:

- (a) The maximum forces that could be applied, irrespective of the time of exertion, to the longitudinal, lateral and directional controls for the different positions of the controls with respect to the pilot's seat. From these tests, the optimum control positions for exerting high forces were derived for each pilot. These positions were then used in subsequent control force tests except for the lateral controls which were moved slightly forward with respect to the optimum position.
- (b) The maximum forces that could be maintained for given periods of time on each of the controls, and
- (c) The time needed in order to apply a large rudder pedal force.

TEST 2 was mainly concerned with the rate of application of control forces. Also, the pilots were asked about the harmonisation of the various control stiffnesses.

#### Results

These have been tabulated and graphed.

PALMER, W.E. *A flight simulator study of the lateral-directional stability requirements of piloted air vehicles.* NA 61H-241, 1961.

A fixed-base simulator study was made of the primary factors which affect pilot opinion of the lateral-directional (Dutch roll) stability of current aircraft. The results indicate the degree of acceptability of damping, airspeed indicators, mach number, rate-of-climb indicators, altimeters and the radar unit.

#### Conclusions

The degree of acceptability of the lateral-directional characteristics of any aircraft can be predicted for a wide range of configurations by the use of two correlation parameters. One specifies the minimum required damping of the lateral oscillation and the other specifies the maximum allowable control yawing moment.

PERRY, D.H. *Flight simulators and the study of aircraft handling characteristics.* RAE TOLS/7, December 1962.

The author describes two simulator studies, one concerned with the problem of speed holding and the other with the handling qualities of a slender delta-wing transport aircraft during instrument landing approaches. Emphasis is placed on (1) the representation of atmospheric turbulence (2) the detailed nature of the task and (3) the sample of pilots used in tests of this nature. Some of the difficulties encountered in providing an adequate simulation of real flight, particularly during take-off, approach and landing are discussed.

PERRY, D.H. *Flight simulation - some aspects of its use for studies of aircraft handling qualities.* RAE TM-Aero-952, 1966.

The experience gained during the use of a simulator for studying the handling qualities of fixed wing and VTOL aircraft is discussed. The problem of simulator validation is considered and examples of comparative studies between flight and simulated flight are given. Examples of some recent investigations are used to illustrate the type of original research studies made on the simulator. More general conclusions regarding the use of simulation for handling qualities work are also given.

PERRY, D.H. and BURNHAM, J.A. *A flight simulator study of difficulties in piloting large jet transport aircraft through severe atmospheric turbulence.* MOD Aeronautical Research Council, London. Report CP-906, September 1965.

A pitch and roll simulator has been used to study the difficulties of flying a representative jet transport through severe storm turbulence. Random atmospheric disturbances of RMS velocity of 15 ft/sec combined with longer term vertical draughts of up to 200 ft/sec were studied during instrument flight. Most pilots had little difficulty in controlling the aircraft despite the severe conditions represented. Some who made power and trim changes freely, however, tended to set up long period oscillations in speed and flight-path similar to those reported in actual flight. The results provide a useful experimental demonstration of the validity of current rough air flying techniques.

QUIGLEY, H.C. *Simulation techniques for the study of V/STOL problems.* AGARDograph 99, 1964.

The author reviews work carried out, and the methods used in V/STOL simulation at the NASA-Ames Research Centre, Moffett Field, California. He refers to other studies in which the techniques and types of simulator are different from those used at Ames.

#### Conclusions

For successful V/STOL simulation:

1. Evaluating pilots must be given a realistic demanding task.
2. Adequate motion and visual cues must be available.
3. When whole-task simulation is used, motion and/or outside world visual cues are required in order to supplement the standard instrument cues.

4. Proper cockpit environment and control systems representative of the aircraft being simulated are required. Since experience with V/STOL simulation is limited, the display and types of motion required for some operations have not, as yet, been optimised.

QUIGLEY, H.C. and HOLZHAUSER, C.A. *Requirement for simulation in V/STOL research aircraft programmes.* Proceedings of Fluid Dynamics Panel Symposium, Delft, Netherlands, April 1974.

The authors discuss the application of flight simulation to aircraft design and development in general. They detail the part simulators play in (a) the development and flight research programme for the Augmented Jet-Flap STOL research aircraft and (b) design studies of advanced VTOL research aircraft. Simulation projects proved significant in helping establish criteria for the aircraft design and in facilitating the study of problems associated with new flight profiles, new methods of control and special emergency conditions.

SADOFF, M. *The effects of longitudinal control-system dynamics on pilot opinion and response characteristics as determined from flight tests and from ground simulator studies.* NASA M-10-1-58A, 1958.

*Subjects*

Two NASA pilots took part.

*Equipment*

A Sabre YF-86D aircraft and a fixed-base Sabre F-86A simulator presenting a random tracking task to the pilot on a CRT.

*Summary*

The results of a fixed-base simulator study of the effects of variable longitudinal control system dynamics on pilot opinion are presented and compared with flight-test data. The control system variables considered included stick force per g, time constant and dead-band or stabiliser breakout force. In general, the fairly good correlation between flight and simulator results shows the validity of the simulator results. However, in the investigation of certain problem areas (e.g. sensitive control system configurations associated with pilot-induced oscillations in flight), fixed-base simulator results did not predict the occurrence of an instability although the pilots found that the system was extremely sensitive and unsatisfactory. If it is desired to predict pilot-induced oscillation tendencies, tests in moving-base simulators may be required. It was found possible to represent the human pilot by a linear pilot analogue for the tracking task. The criterion used to adjust the pilot analogue was the RMS tracking error of one of the human pilots on the simulator. Results of the pilot-analogue study indicated that, both for poor airplane dynamics and for a region of good airplane dynamics, the pilot response characteristics are approximately the same.

SADOFF, M. *A study of a pilot's ability to control during simulated stability augmentation systems failures.* NASA TN-D-1552, 1962.

*Equipment*

The centrifuge at NADC, Johnsville, was used.

*Subjects*

Four test pilots took part.

*Method*

To provide some information on a pilot's ability to control a vehicle during sudden SAS failures of the longitudinal control system, a fixed and moving-base simulator study was conducted. The SAS failures were simulated simply by varying the vehicle dynamics suddenly. No attempt was made to simulate "hard-over" failures. No failures were initiated while the pilot was occupied with a pitch attitude tracking task, since the consequences of SAS failures were anticipated to be more serious when the pilot was required to control the vehicle attitude, altitude or flight path precisely.

*Conclusions*

The results show the effects of failure of a stability augmentation system on the pilot's ability to control while engaged in a simple tracking task and they suggest that moving simulators provide a more realistic evaluation of the transient effects of stability-augmentor failures. Simulator motions generally interfered with the ability of the pilots to adapt to the failures. A pencil-type side-arm controller proved easier to use than a conventional centre stick in coping with pitch damper failures at the higher short-period frequencies. The use of simple pilot models in the analysis and prediction of the transient effects of stability augmented failures provided encouraging results.

SMITH, R.P., LYTWYN, R.T. and WHITE, F. *Analysis, simulation, and piloted performance of advanced tandem-rotor helicopters in hover.* AHS Preprint 843, 1974.

To explore the parameters of possible future tandem-rotor helicopters which are likely to affect aircraft performance during precise hover missions, four tandem-rotor helicopters with gross weight capabilities of 50,000, 80,000, 120,000 and 200,000 lbs were defined parametrically in sufficient detail to permit stability and control evaluation and piloted simulations. Automatic stabilisation and hover-hold functions were then synthesised for each configuration. Several command systems were established specifically for the piloted hover-hold missions. The hover performance was established analytically including hover-hold in turbulence with automatic control functions alone and the piloted hover capability without automatic hold functions. The 50,000 lb configuration was used to generate similar performance results with the Northrop Large Amplitude/Wide Angle Visual simulator. The simu-

lator results were then compared with the analysis to establish the degree of validity of the selected analytical approaches.

SNYDER, C.T., BRAY, R.S., DRINKWATER, F.J. and FORREST, R.D. *Simulation studies for development of certification criteria applicable to SST take-off*. NASA SP-270, 1971.

A variety of airplane configurations was studied in this programme. Nearly 2,000 take-offs and 300 landings were simulated. Engine failure on take-off testing of high induced-drag SST designs confirmed the need for more stringent take-off speed requirements. However, these tests demonstrated that proposed requirements, intended to provide additional protection, were over-conservative and economically penalising. New minimum requirements were defined and agreed on during joint testing by British, French and US airworthiness authorities. During surprise take-off tests, the sequence of application of deceleration devices (throttles, brakes and spoilers) was found to differ from that commonly assumed in the certification process of determining the accelerate-stop distance and has the effect of increasing the stopping distance. The effects of this difference could be amplified for SST airplanes.

SNYDER, C.T. and JACKSON, C.T. *A piloted simulator study of take-off performance and handling qualities of a double-delta supersonic transport*. NASA TN-D-4396, 1968.

The TO characteristics of a generalised double-delta SST configuration were investigated in a fixed-base simulator equipped with an external visual display. The purpose was to investigate performance and handling qualities, identify possible problem areas, and assist in the evaluation of certification requirements to be used during the development of the SST. Comparisons of the TO characteristics are drawn between the simulated SST and a reference subsonic jet transport (SJT). The augmented SST exhibited:—

1. Excellent performance during normal TOs.
2. A greater probability of nacelle or tail scrapes than the SJT, indicating a need for more time for the rotation manoeuvre, a longer landing gear on the design tested or higher lift-off speeds.
3. Initial climb characteristics which were acceptable but unpleasant due to a tendency toward pitch "wandering" aggravated by negative speed-drag stability.
4. Good lateral-directional and engine-out characteristics and
5. A performance sensitivity to lift-off speed abuse during marginal-thrust TOs, which indicated the need for review of the present airworthiness criterion regarding one-engine-out first-segment climb.

STAPLEFORD, R.L., HEFFLEY, R.K., JEWELL, W.F., LEHMAN, J.M., HYNES, C.S. and SCOTT, B.C. *A STOL airworthiness investigation using a simulation of a deflected slipstream transport*. Vol.2: *Simulation data and analysis*. NASA TM-X-62393, 1974.

The authors describe the simulation procedures used in analysing the airworthiness criteria for STOL transport aircraft with deflected airstream lift augmentation. The aircraft simulated was the four-engine, turbo-prop Breguet 941S. The data obtained includes performance measures, pilot comments and pilot opinion ratings. An analysis of glideslope tracking and of the flare manoeuvre is included. Reference should be made to Stapleford, R.L. et al (1974) and to Heffley, R.K. et al (1974).

Stapleford, R.L., Heffley, R.K., Rumold, R.C., Hynes, C.S. and Scott, B.C. *A STOL airworthiness investigation using a simulation of a deflected slipstream transport*. Vol.1: *Summary of results and airworthiness implications*. NASA TM-X-62392, 1974.

Heffley, R.K., Jewell, W.F., Stapleford, R.L., Craig, S.J., Hynes, C.S. and Scott, B.C. *A STOL airworthiness investigation using a simulation of a deflected slipstream transport*. Vol.3: *Breguet 941S simulation model*. NASA TM-X-62394, 1974.

STAPLEFORD, R.L., HEFFLEY, R.K., RUMOLD, R.C., HYNES, C.S. and SCOTT, B.C. *A STOL airworthiness investigation using a simulation of a deflected slipstream transport*. Vol.1: *Summary of results and airworthiness implications*. NASA TM-X-62392, 1974.

#### Notes

A series of three simulations were conducted under a joint NASA FAA programme at the NASA Ames Research Centre, Moffett Field, Calif., using the Flight Simulator for Advanced Aircraft. The aircraft simulated was the French Breguet 941S which is a four-engine, turbo-prop transport plane in the 50,000 lbs gross weight class.

#### Method

A simulator study of STOL aircraft was carried out using deflected slipstream, transport aircraft characteristics. The subjects considered were (1) the approach, (2) flare and landing, (3) circuits and (4) take-off phases of flight. The results are summarised and possible implications with regard to airworthiness criteria are discussed. A data base is provided for future STOL airworthiness requirements and a preliminary indication of potential problem areas is developed. Comparison of the simulation results with various proposed STOL criteria indicates significant deficiencies in many of these criteria. For volumes 2 and 3 of this study reference should be made to Stapleford, R.L. et al (1974) and Heffley, R.K. et al (1974).

Stapleford, R.L., Heffley, R.K., Jewell, W.F., Lehman, J.M., Hynes, C.S. and Scott, B.C. *A STOL airworthiness investigation using a simulation of a deflected slipstream transport*. Vol.2: *Simulation data and analysis*. NASA TM-X-62393, 1974.

Heffley, R.K., Jewell, W.F., Stapleford, R.L., Craig, S.J., Hynes, C.S. and Scott, B.C. *A STOL airworthiness investigation using a simulation of a deflected slipstream transport*. Vol.3: *Breguet 941S simulation model*. NASA TM-X-62394, 1974.

STINNETT, G.W. *Pilot simulator studies of new aircraft missions*. AGARDograph 99, 1964.

Future research in precise flight-path control is essential for the solution of problems posed by SST low altitude high-speed missions and blind landing tasks. The writer outlines the part simulators will play in finding solutions, and the usefulness of a motion system in providing pilot cues. Other components under development or evaluation are instrument displays whose function it is to provide the pilot with sufficient information to enable him to perform particular flight-path control tasks in IFR conditions.

TAYLOR, L.W. and DAY, R.E. *Flight controllability limits and related human transfer functions as determined from simulator and flight tests*. NASA TN-D-746, 1961.

*Equipment*

A fixed-base simulator with a side-arm and centre-stick controller. The display consisted of a moving line on a 17-inch oscilloscope presenting angles of attack, sideslip and bank.

A centrifuge simulator.

Sabre types YF-86D and YF-86E were used for the flight tests.

*Method*

A simulator study and limited flight tests were conducted to find the levels of static stability and damping necessary for pilot control of the pitch, roll and yaw attributes of an aircraft for a short period of time. Novel piloting techniques were found which enabled the pilot to control the aircraft in conditions that were otherwise uncontrollable. The influence on the controllability limits of the more important aerodynamic coefficients and other factors, such as learning and the interruption of the pilot's display, was also investigated. Information concerning human transfer functions applicable to marginally controllable tasks is presented, and this should help in assessing the controllability of any specific configuration.

TOMLINSON, B.N. *The simulation of turbulence and its influence on the pilot*. RAE TM: Aero 1314, 1971.

The author deals with four topics, (1) how turbulence disturbs an aircraft (2) how turbulence affects the pilot (3) why turbulence is simulated and (4) how turbulence is simulated. Turbulence is an essential element in the simulation of aircraft handling characteristics because it affects the pilot's control activity, his performance and his workload. Three factors contribute to a good simulation of flight in turbulence (1) an adequate mathematical model of the aircraft dynamics (2) a source of representative atmospheric turbulence and (3) stimulation of the pilot's senses by motion cues. Simulated turbulence is often obtained from white noise generators, but the output from these is Gaussian in character. A better reproduction of turbulence, particularly the intermittency and frequency of occurrence of peaks, may be obtained by using a modified gust generator. To reproduce rough air characteristics, the RAE (Aero Department) took a source of white noise and filtered the output to match power spectra of atmospheric turbulence measured in flight. Provision of motion cues is essential for a realistic representation of flight in turbulence. Large amplitude motion systems may be required if relatively low frequency accelerations are to be reproduced, and the system should also be capable of responding at frequencies of up to 5-10 Hz.

VINCENT, J.H. *STOL tactical aircraft investigation, Vol.5, Part 2: Flight control technology: Piloted simulation of a medium STOL transport with vectored thrust mechanical flaps*. Final Technical Report, June 1971-Dec 1972. AFFDL TR-73-19, 1973.

Fixed-base simulation studies were conducted to evaluate control systems for a STOL tactical transport equipped with vectored thrust. Unaugmented aircraft flying qualities were found to be unacceptable. However, an augmented control system configuration was found to give excellent flying qualities and satisfactory behaviour following engine or control system component failure.

VINJE, E.W. *Flight simulator evaluation of control-moment usage and requirements for V/STOL aircraft*. AHS Pre-print 743, 1973.

Fixed and moving-base simulator experiments were conducted to evaluate V/STOL aircraft control-moment usage for hovering and low-speed flight tasks. The longitudinal, lateral, and longitudinal plus lateral control-moments used, with effectively unlimited moments available, were measured for a variety of configurations. The percent times that various levels of control-moments were exceeded were computed from the control-moment usage data. Results show the effects of control-moment usage for (1) aircraft and control system configuration (2) aircraft flying qualities level (3) turbulence intensity and (4) flight task. The relationship between individual axis and simultaneous pitch and roll control-moment usage is also discussed.

VOMASKE, R.F., SADOFF, M. and DRINKWATER, F.J. *The effect of lateral-directional control coupling on pilot control of an airplane as determined in flight and in a fixed-base flight simulator*. NASA TN-D-1141, 1961.

*Equipment*

The plane used was a variable-stability F-86E (Sabre). The fixed-base simulator had a cockpit layout similar to the Sabre and, in addition to the conventional centre stick, it had a three-axis side-arm controller.

### Subjects

Three NASA research pilots took part.

### Summary

A flight and fixed-base simulator study was made of the effects of aileron-induced yaw on pilot performance of lateral control. A wide range of favourable and adverse aileron-induced yaw was investigated at several levels of Dutch-roll damping.

### Conclusions

1. The optimum aileron-induced yaw differed, statistically, only slightly from zero aileron-induced yaw.
2. Increase of Dutch-roll damping increased the range of aileron-induced yaw considered satisfactory, acceptable or controllable.
3. The results of the simulator tests were essentially identical to the flight results and indicate that the absence of motion cues did not markedly affect pilot opinion, presumably because of the presence of strong visual cues.
4. Correlation of the results of this study with other data reveal several parameters which may be useful for predicting lateral handling characteristics.
5. Comparison of the results obtained using the side-arm controller with those for the centre stick and rudder pedals indicated that, for coupling problems associated with a large increase in favourable aileron yaw, the side-arm controller accentuated the control problem. This may be attributable to the cross-control technique required. This is more difficult to apply with the side-arm controller.

WATANABE, A. and HORIKAWA, Y. *Simulation study on flare control system by optimisation theory*. National Aerospace Laboratory, Tokyo, Japan. NAL TR-312, 1973. (In Japanese).

The simulation of a flare control system for an automatic landing system was conducted. Digital simulation analyses were done for three systems. The simulation showed that an exponential flight path was applicable to the flare control system. The characteristics of the flight paths and the performance of the systems are discussed.

WHITE, M.D. and COOPER, G.E. *A piloted simulation study of operational aspects of the stall pitch-up*. NASA TN-D-4071, 1967.

A simulator study was conducted to investigate the stalling characteristics of transport-type planes having localised instabilities associated with the pitching moment variations at stall.

### Conclusions

1. Whether a deep stall could develop following stall penetration depended on differing operational conditions over a wide range of pitching moment variations. With large "bumps" the plane tended to be projected into deep stall angles of attack before the pilot could check the motion. With small unstable "bumps" the plane tended to drift into deep stall angles with no obvious cues to the pilot.
2. The longitudinal stability at angles of attack above the unstable "bump" was of primary importance in defining the depth of the stall penetration.
3. In both the entry into and the recovery from stall, the lack of positive information regarding stall status from the standard instrument display of pitch attitude compromised the ability of the pilot to regain unstalled flight quickly.
4. The tendency of the pilot to match the magnitude of the corrective control to the severity of the motion in stall entry compensated for differences in rate of stall entry associated with different pitching moment "bumps".
5. Available data on lateral-directional characteristics at deep stall angles indicated that maintaining wings-level flight and avoiding a spin would be a serious problem. This problem has increased importance in relation to the deep stall because of the prolonged commitment to stalled flight.
6. In view of the probable serious consequences of penetration into a deep stall, it is considered mandatory that adequate safeguards be provided against inadvertent stall entries. A philosophy of stall safeguard featuring two levels of stall warning, originally proposed for use with gross instabilities in the deep stall, is considered applicable with localised instabilities.

WILCOCK, T. and THORPE, A.C. *Flight simulation of a Wessex helicopter: A validation exercise*. RAE TR-73096, 1973.

A Westland Wessex simulation was performed to evaluate the limitations of a simplified mathematical representation of the handling qualities of the helicopter and the validity of the simulation environment. By limiting the scope of the simulation to the normal flying regime of the helicopter, an adequate representation of the Wessex was possible. Presentation of the handling behaviour was satisfactory in pitch and roll. Some difficulties were experienced in the representation of yawing behaviour and of height control near the hover, and these were attributed to the inadequate motion capability of the simulator. However, the results gave a measure of confidence for a future Lynx simulation and identified the areas for caution in interpreting the results.

WILCOCK, T. and TOMLINSON, B.N. *Flight simulation in helicopter and V/STOL research*. Proceedings of Second R.Ae.S. Flight Simulation Symposium, London, England, May 1973.

The authors describe behavioural ways in which helicopters and V/STOL aircraft differ from conventional planes and they discuss the implications of these differences for simulation, mainly in the context of research into handling and operational problems. Their inferences do not necessarily apply to training simulators. They describe the Aerodynamics Flight Division simulator at RAE (Bedford), and they discuss a number of V/STOL aircraft and helicopter simulations carried out there during the last decade, including a report on a current STOL programme.

*Conclusions*

- (1) *Visual cues* require an increased field of view in azimuth and improved picture quality for landing.
- (2) *Motion cues*. The increase in the complexity of the pilot's control task emphasises the value of motion and the need for new axes (e.g. yaw), and the control of height without associated pitch changes may require increased heave travel. Other linear movements are also growing in importance.
- (3) *Mathematical model*. Reliable data for complex configurations may be difficult to obtain. Models may be difficult to set up and check. New ideas and new measurements on turbulence should be incorporated into simulators.

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